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* President of the Paleontological Society.

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CORRECTIONS AND INSERTIONS

Contributors to volume 38, have been invited to send corrections and insertions to be made in their papers, and the volume has been scanned with some care by the Editor. The following are such corrections and insertions as are deemed worthy of attention:

Page 194, line 6 from bottom, *for* "William T. Miller" *read* William J. Miller
" 209, at bottom of page, *insert* One of the sessions was held jointly with the Eastern Section of the Seismological Society of America
" 443, line 2 below "Introduction," *for* "semiarid" *read* semi-arid
" 443, line 4 from bottom, *for* "crosses" *read* cross
" 448, line 2 from top, *for* "formed" *read* formerly
" 449, line 3 from top, *omit* comma after "Above"
" 483, line 6 from bottom, *for* "vertical" *read* vortical
" 483, bottom line, *for* "vertical" *read* vortical
" 489, line 4 from top, *for* "terrace" *read* terrain
" 529, title of figure 8, *for* "Lava-yow" *read* Lava-flow
" 574, line 9 from top, *for* "fauld-scarp" *read* fault-scarp
" 578, line 1 from top, *for* "Mississipian line" *read* Mississippi line
" 578, line 4 from top, *for* "figures 2, 3 and 5" *read* figures 2 and 3
" 731, line 15 from bottom, *for* "upper copper-bearing" *read* Upper Copper-bearing
" 732, line 6 from bottom, *for* "migmatities" *read* migmatites
" 733, line 6 from bottom, *for* "1926" *read* 1916
" 777, at bottom of page, *omit* "in a private communication"
" 802, line 4 from bottom, *for* "quartz" *read* quartzite
" 845, line 5 from bottom, *for* "side and north" *read* side, north

‡ Bearing imprint [From BULL. GEOL. SOC. AM., Vol. 38, 1926].

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 38, PP. 1-192, PLS. 1-7 MARCH 30, 1927

PROCEEDINGS OF THE THIRTY-NINTH ANNUAL MEETING OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT MADISON, WISCONSIN, MONDAY, TUESDAY, AND WEDNESDAY, DECEMBER 27, 28, AND 29, 1926

CHARLES P. BERKEY, *Secretary*

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Session of Monday Morning, December 27

The Thirty-ninth Annual Meeting of the Geological Society of America was called to order in the Auditorium of Agricultural Hall, University of Wisconsin, Madison, Wisconsin, at 9.05 a. m., by President Lawson. Brief introductory remarks were made by the chairman, who called attention to the accommodations for caring for the different affiliated and associated societies meeting at the same time, and to the method of handling the principal program.

Address of welcome by E. A. Birge

Doctor Birge, President *emeritus* of the University of Wisconsin, representing President Frank, made the following address of welcome:

In the necessary absence of President Frank, I have the duty and the pleasure of welcoming you to the University of Wisconsin. I need not make many words in welcoming the societies which have assembled here in council. We are honored by your presence, by receiving as our guests societies so important and men so distinguished in a great field of science. We hope that you may find adequate arrangements for your comfort and ample facilities for scientific intercourse, so that you may leave us with the pleasant thought that you have fulfilled the anticipations with which you came.

So much of official greeting from the University to the geological societies here assembled. May I add a more personal word, expressing the especial pleasure with which I welcome those who are devoted to a science cognate to that which has always claimed my own interest? Let my greeting go primarily to men and women rather than to societies, for I find something a little unsympathetic in official titles. An academy of sciences may keep all of its dignity and yet through ill fortune become a place where science is kept in a sort of cold storage; but that can not happen to associations of active and eager men and women. Have you ever noticed how in early days, before the several sciences had developed, the names of the academies often emphasized the real or supposed personal qualities of their members? There were the *Ardenti* of Naples and the *Addormentati* of Genoa. Sometimes the name had a touch of the far-fetched or even of the grotesque, like the famous Roman *Accademia dei Lincei*, founded in 1603. But of all those older bodies the best named, to my thinking, was the society established at Leipsic in 1651—the *Academia Naturæ Curiosorum*, the academy of those who are keen about nature. One can readily imagine a very dull meeting of a scientific association; but when *naturæ curiosi* get together, there can not fail to be both pleasure and profit in the meeting. So I welcome you in

that spirit, as an assembly of men and women who are keen about nature. I am sure that you come together with us as *naturæ curiosi,* and that your meeting will result not merely in greater information or even larger ideas. It will serve far more important ends, since when we separate both you and we will be *naturæ curiosiores*—more keen about nature than when we met.

May I add another word about a natural object in the immediate neighborhood which has both a geological and a personal interest for us? You will not fail to notice the boulder which has been set up on the hill just behind this building in which we are meeting, close beside the path to the dormitory in which you are housed. You will certainly read the inscription on the tablet:

CHAMBERLIN ROCK

This tablet commemorates the services to Wisconsin of

THOMAS CHROWDER CHAMBERLIN

Leader in science and education

State Geologist of Wisconsin, 1873-1882

President of the University, 1887-1892

As State Geologist he conducted a survey distinguished for high scientific and economic value

As President he made the spirit of research effective in the organization and life of the University

He first distinguished and named the drifts left in this region by successive ice-advances. This boulder, brought by the continental glacier from ancient Pre-Cambrian bedrock in Canada, was deposited here in the Wisconsin or latest glacial drift, of which this hill is a part.

You will notice the limitations expressed in this inscription. The monument does not attempt to commemorate the man; it does not even commemorate his entire work, for it makes no mention of those studies of wider scope on which so much of his permanent fame will rest. Its purpose is at once more modest and more local. It testifies to the honor and affection with which Wisconsin remembers the work of Dr. Chamberlin in this State and on this campus.

Could we have found for this purpose a memorial more appropriate than this great boulder? It was brought from distant Canada by the ice-invasion to which Dr. Chamberlin gave the name Wisconsin. It was deposited here, on the summit of this moraine hill, standing midwise in the University campus. And here we have set it up, where it shall always challenge the attention of the visitor. It looks out over a lake, over a landscape shaped by the geological forces which Dr. Chamberlin corre-

lated and named. It stands central in the grounds of the University whose material and spiritual welfare he so greatly advanced, and I am able to make this first public announcement of the completed memorial to you, his comrades in the science which has received so much from him and the van of whose progress he still leads.

REPORT OF THE COUNCIL

The report of the Council was presented by the Secretary as follows:

To the Geological Society of America, in thirty-ninth annual meeting assembled:

The regular annual meeting of the Council was held at New Haven, Connecticut, in connection with the meeting of the Society, December 28-30, 1925. A special meeting was held in New York City on October 16, 1926.

The details of administration for the thirty-ninth year of the existence of the Society are given in the following reports of the officers:

PRESIDENT'S REPORT

To the Council of the Geological Society of America:

The President's report for the year ending November 30, 1926, is as follows:

The absence of the President from the United States for the greater part of the year has prevented his giving that attention to the affairs of the Society which the office demands. He finds on his return, however, that the Society continues to prosper. Many of the duties of the President were discharged by the First Vice-President. The Secretary has maintained the usual high efficiency of his office, and the Society has suffered so little from the President's absence that he has begun to suspect that his office is purely honorary. The membership of the Society continues to increase on a steady, upward curve, which is, however, probably not as steep as the curve of the numerical growth of geologists in North America, nor so steep as the curve of growth of other national scientific societies. There are many active geologists who do not yet enjoy fellowship in the Society, who would be a source of strength to it if admitted. A statement regarding additions and losses to the membership for the current year will be found in the Secretary's report.

The Cordilleran Section of the Society has been functioning successfully now for 25 years, but has no constitutional recognition. It would seem proper that the existence of the Section should have authorization

in the Constitution, and that it should have representation in the Council. A special committee appointed to consider this matter will submit a recommendation dealing with it. No satisfactory solution has yet been found for the conflict of interest which arises when Section E of the American Association for the Advancement of Science meets simultaneously with the Geological Society of America in different cities; but a beginning of closer cooperation has been made by the agreement of the Council to print the abstracts and announce the program of Section E, and by the attempt of the respective secretaries to avoid conflicting dates for the principal features of the two programs.

The Treasurer's report shows that the finances of the Society are in a satisfactory state. The Bulletin reflects the activity of the Fellows in various departments of geology. The contribution to science which it represents is most creditable, but the production relatively to the number of Fellows is not so large as it was earlier in the Society's history.

It is especially gratifying to be able to report at this time that a medal has been established and liberally endowed by the generosity of a fellow member of the Society, Dr. R. A. F. Penrose, Jr. The purpose is to make it possible to honor in an appropriate manner exceptional merit and eminence in research in pure geology. The deed of gift specifies that the medal is to be awarded on occasion only for distinguished attainment and contribution in an outstanding manner to the advancement of the science of geology.

The Society is indebted to the Fellows who have given their services on various committees. The purpose and personnel of the committees functioning this year are indicated in the following list:

Membership Committee: U. S. Grant (Chairman), W. H. Twenhofel, Nelson H. Darton.

Program Committee: Charles K. Leith (Chairman), Charles P. Berkey, Frank R. Van Horn, R. S. Bassler, Sydney H. Ball, David White.

Committee on Foreign Correspondents: James F. Kemp (Chairman), Arthur P. Coleman, William B. Scott, David White.

Committee on Exchanges: Charles Schuchert (Chairman), Edward W. Berry, Henry S. Washington.

Finance Committee: Fred E. Wright, Joseph Stanley-Brown, Richard A. F. Penrose, Jr.

Committee on Publication: David White, Florence Bascom, Joseph Stanley-Brown, Charles P. Berkey, Edward B. Mathews.

Local Committee for the Madison Meeting: William H. Twenhofel (Chairman), A. N. Winchell, E. F. Bean.

Penrose Medal Committee: Richard A. F. Penrose, Jr., Charles P. Berkey.

Committee on Penrose Medal Procedure: Edward B. Mathews (Chairman), David White, Fred. E. Wright.

During the year several important appointments have been made of representatives and delegates to scientific meetings and to represent the Society at public functions and celebrations, as follows:

Fourteenth International Geological Congress: Delegates, Andrew C. Lawson (Chairman), William B. Scott, Arthur P. Coleman, James F. Kemp, Charles K. Leith, Edward B. Mathews, Richard A. F. Penrose, Jr., Alan M. Bateman, George P. Merrill, Nelson H. Darton.

Third Pan-Pacific Science Congress: Delegates, Frank D. Adams (Chairman), Herbert E. Gregory, Harry Fielding Reid, Thomas Wayland Vaughan.

International Conference on Bituminous Coal: Representatives, George H. Ashley, David White, Charles R. Fettke.

Twenty-ninth Annual Convention of The American Mining Congress: Representatives, Joseph T. Singewald, Jr., Gerald F. Loughlin, Marius R. Campbell, Ernest F. Burchard, E. L. De Golyer.

The Joseph A. Holmes Safety Association: Delegate, John J. Rutledge.

The Society of Economic Geologists: Waldemar Lindgren.

Centennial Celebration of the Founding of Western Reserve University: Delegate, John A. Bownocker.

Inauguration of Arnold Bennett Hall as President of the University of Oregon, and Semi-Centennial of the Founding of the University: Delegates, Warren DuPre Smith, Harold E. Culver.

Respectfully submitted, ANDREW C. LAWSON,
President.

SECRETARY'S REPORT

To the Council of the Geological Society of America:

The Secretary's annual report for the year ending November 30 1926, is as follows:

Meetings.—The proceedings of the annual meeting of the Society, held at New Haven, Connecticut, December 28-30, 1925, have been recorded in volume 36, pages 1-206 of the Bulletin. Those of the Cordilleran Section, pages 207-224 of the Bulletin; of the Paleontological Society, pages 225-254; of the Mineralogical Society of America, pages 255-260, of the same volume.

Membership.—During the last year the Society has lost by death eight Fellows—William O. Crosby, John B. Harrison, James F. Kemp, William Kennedy, Frank H. Knowlton, Willis T. Lee, John C. Smock,

and William L. Uglow. The names of the thirteen candidates elected at the New Haven meeting have been added to the printed list. One name has been dropped from the list for non-payment of dues. There have been no resignations. The present enrollment of the Society is 515. Twenty-one candidates for Fellowship are before the Society for election, three for correspondentship, and a number of applications are under consideration by the Council.

Distribution of the Bulletin.—During the past year there have been sent out to domestic subscribers 177 copies and to foreign subscribers 76 copies of the Bulletin, 40 going to new subscribers. This shows an increase in subscriptions over last year of 20 copies. Eight volumes have been distributed gratis, as follows: Library of Congress, the Government Geological Surveys of the United States, Canada, Mexico, the Bureau of Science, Manila, Philippine Islands, the Smithsonian Institution, Washington, D. C., the Case Library, Cleveland, Ohio, and the Columbia University Library, New York City. The present exchange list comprises 51 addresses. The receipts of this office, including subscriptions to and sales of the Bulletin and separate brochures therefrom, are summarized as follows:

Detailed Financial Statement of the Secretary's Office

RECEIPTS

Regular subscriptions	$2,304.00
Irregular sales	1,066.82
Geological Magazine	65.25
Post and express refunds	56.84
Group portrait	5.00
Authors' separates	173.23
Exchange added to checks	1.80
Miscellaneous	45.00
Total receipts from all sources	$3,717.94
Amount forwarded to Treasurer	3,717.94
Endowment of the Penrose Medal	5,000.00

DISBURSEMENTS

On account of administration:	
Printing expenses, New Haven meeting	$377.00
Printing for 1926	100.44
Clerical help for 1926	400.00
Postage	135.19
Exchange on checks	3.15
Telegrams and telephone calls	8.85
Addressograph plates	4.66
Miscellaneous supplies	2.69
Rent of Council room at hotel, New Haven	10.50

Filing cabinet	$61.87
Rent of safe-deposit box	5.00
Total	$1,109.35
On account of Bulletin:	
Postage and express charges	116.24
Carfare	1.05
Notary fees	.50
Total	$117.79

Respectfully submitted, CHARLES P. BERKEY,
Secretary.

TREASURER'S REPORT.

To the Council of the Geological Society of America:

The Treasurer herewith submits his report for the year ending November 30, 1926.

The membership of the Society on December 1, 1925, consisted of 404 paying annual dues, 88 Life members, and 16 Correspondents. Thirteen new members qualified during the year, 3 of them commuting for life. Three Correspondents were also elected. One Life member and 7 Annual members have died during the year and one was dropped for the non-payment of dues.

As the books close the membership consists of 406 Annual members, 90 Life members, and 19 Correspondents, making a total of 515.

The fees receivable at the beginning and close of the year are as follows:

	Receivable Jan. 1, '26	*Collected to Nov. 30, '26*	*Due Dec. 1, '26*
Fees of delinquents: '23, '24, '25	$330.00	$230.00	$70.00
Fees of 1926 (417)	4,170.00	3,930.00	140.00
			$210.00
Initiation fees (13)	130.00	130.00	
	4,630.00	4,290.00	
Adjustments	80.00*	230.00†	
	$4,550.00	$4,520.00	
Less 3 Life commutations	30.00		
	$4,520.00		

RECEIPTS

Cash on hand December 1, 1925		$3,418.35	
Annual dues:			
1923 (4)	$40.00		
1924 (4)	40.00		
1925 (15)	150.00		
1926 (393)	3,930.00		
1927 (2)	20.00		
		4,180.00	
Initiations (13)		$130.00	
Initiation and dues paid in error (refunded)		20.00	
Life commutations (3)		450.00	
Case Library accessions		150.00	
Interest:			
On investments	$1,720.00		
On deposits	181.47		
		1,901.47	
Bond redeemed (American Agricultural Chemical at 103)		1,030.00	
Foreign exchange added to checks		.20	
Received from Secretary:			
Bulletin sales	$3,370.82		
Geological Magazine	65.25		
Group portrait	5.00		
Authors' separates	173.23		
Exchange added to checks	1.80		
Postage and express refunds	56.84		
Miscellaneous	45.00		
		3,717.94	
			$14,997.96

DISBURSEMENTS

Secretary's Office:			
Administration	$1,109.35		
Bulletin	117.79		
Geological Magazine	65.25		
Allowance	1,000.00		
		$2,292.39	
Treasurer's Office:			
Expenses	$105.75		
Clerk	150.00		
		255.75	
Publication of Bulletin:			
Printing	$3,861.15		
Engraving	407.06		
Editor's allowance	250.00		
		4,518.21	

*Written off for delinquencies	$40.00	
Written off for death	20.00	
Written off for non-contributing	20.00	
		$80.00*
†Received prior to 1926	20.00	
Present delinquencies	210.00	
		230.00†

Mineralogical Society of America		$114.00	
Cordilleran Section		54.35	
Refund of dues paid in error		20.00	
Investments:			
2 Canadian Pacific Railway bonds	$1,930.00		
2 Westinghouse Electric and Mfg. Co.	2,004.00		
2 Bethlehem Steel Corporation	2,019.00		
Accrued interest	35.83		
		5,988.83	
			$13,243.53
Balance in bank December 1, 1926			1,754.43
			$14,997.96

Respectfully submitted,

EDWARD B. MATHEWS,
Treasurer.

EDITOR'S REPORT

To the Council of the Geological Society of America:

The following tables cover statistical data for the thirty-seven volumes thus far issued:

ANALYSIS OF COSTS OF PUBLICATION

Cost	Average—Vols. 1-35	Vol. 36	Vol. 37
	pp. 732 pls. 29	pp. 707 pls. 10	pp. 692 pls. 20
Letter press	$1,895.32	$2,737.89	$2,852.45
Illustrations	436.82	528.90	414.56
Paper	404.10	411.96	502.76
Total	$2,736.24	$3,678.75	$3,769.77
Average per page	$3.74	$5.06	$5.45

CLASSIFICATION OF SUBJECT-MATTER

Volume	Areal geology	Physical geology	Glacial geology	Physiographic geology	Petrographic geology	Stratigraphic geology	Paleontologic geology	Economic geology	Official matter	Memorials	Unclassified	Total
	Number of pages											
1.....	116	137	92	18	83	44	47	..	60	4	4	593+xii
2.....	56	110	60	111	52	168	47	9	55	1	7	662+xiv
3.....	56	41	44	41	32	158	104	..	61	15	1	541+vii
4.....	25	134	38	74	52	52	14	..	47	32	2	458+xii
5.....	138	135	70	54	28	51	107	..	71	14	9	665+xii
6.....	50	111	75	39	71	99	1	..	63	25	4	538+x
7.....	38	77	105	53	40	21	123	4	66	28	13	558+x
8.....	34	50	98	5	43	67	58	14	79	8	...	446+x
9.....	2	102	138	...	44	28	64	16	64	12	...	460+x
10.....	35	33	96	37	59	62	68	28	84	27	17	534+xiii
11.....	65	110	21	10	54	31	188	7	71	60	46	651+xii
12.....	199	39	55	53	24	98	5	5	70	2	...	538+xi
13.....	125	17	13	24	28	116	42	4	165	32	29	583+xii
14.....	48	47	48	59	183	118	22	1	80	14	1	609+xi
15.....	26	124	3	94	36	267	...	..	77	17	3	636+x
16.....	64	111	78	30	102	141	19	..	67	22	15	636+xiii
17.....	49	161	41	84	47	294	27	..	71	9	2	785+xiv
18.....	16	164	141	5	29	246	5	..	68	40	3	717+xii
19.....	106	108	29	66	30	155	32	..	56	15	20	617+x
20.....	43	54	35	29	37	45	303	8	60	3	132	749+xiv
21.....	72	234	75	48	85	70	106	1	111	11	10	823+xvi
22.....	23	54	28	28	23	403	74	..	63	49	1	747+xii
23.....	75	52	126	108	19	145	134	..	66	32	1	758+xvi
24.....	18	57	96	57	49	160	106	23	133	53	3	737+xviii
25.....	34	211	54	32	156	9	175	..	108	9	22	802+xviii
26.....	...	72	23	11	56	90	148	..	54	44	6	504+xxi
27.....	1	59	125	31	146	20	271	2	73	24	5	739+xviii
28.....	25	273	70	69	78	200	55	39	94	110	14	1005+xxii
29.....	3	107	62	15	127	169	64	..	73	57	21	679+xix
30.....	160	3	41	9	5	36	205	16	73	59	50	644+xiii
31.....	1	80	19	4	13	45	22	21	69	97	79	450+xviii
32.....	73	47	7	27	63	51	77	17	105	2	37	488+xviii
33.....	39	166	160	47	97	107	101	3	91	41	31	862+xxi
34.....	20	256	73	2	39	149	48	..	89	38	64	778+xx
35.....	44	72	17	83	70	140	269	..	76	46	79	896+xxii
36.....	26	112	27	59	108	103	77	1	74	116	4	707+xx
37.....	53	101	8	8	16	111	126	43	74	126	1	667+xviii

Respectfully submitted,

JOSEPH STANLEY-BROWN, *Editor.*

The foregoing report is respectfully submitted.

THE COUNCIL.

December, 1926.

ELECTION OF AUDITING COMMITTEE

The printed report of the Council was distributed to all members in attendance, and action was delayed on acceptance of the report until such time as an Auditing Committee could examine the accounts of the Treasurer and make report. An Auditing Committee was then named, consisting of Henry B. Kummel, Edward W. Berry, and Gerald F. Loughlin.

ELECTION OF OFFICERS, REPRESENTATIVES, CORRESPONDENTS, AND FELLOWS

The Secretary then read the result of the ballot for officers of the Society for the year 1927, and representatives on the National Research Council, and of the ballot for Correspondents and Fellows. The following were declared elected:

President:

ARTHUR KEITH, Washington, D. C.

First Vice-President:

CHARLES K. LEITH, Madison, Wisconsin

Second Vice-President:

DOUGLAS W. JOHNSON, New York City

Vice-President to represent the Paleontological Society:

WILLIAM A. PARKS, Toronto, Canada

Vice-President to represent the Mineralogical Society:

AUSTIN F. ROGERS, Stanford University, California

Secretary:

CHARLES P. BERKEY, New York City

Treasurer:

EDWARD B. MATHEWS, Baltimore, Maryland

Editor:

JOSEPH STANLEY-BROWN, New York City

Councilors (1927-1929):

H. FOSTER BAIN, New York City
HENRY B. KUMMEL, Trenton, New Jersey

Representatives on the National Research Council (July 1, 1927, to June 30, 1930):

WILLIAM J. MEAD, Madison, Wisconsin
DONNEL F. HEWETT, Washington, D. C.

DETROIT PUBLIC LIBRARY

CORRESPONDENTS

FRANCIS ARTHUR BATHER, London, England. Keeper, Department of Geology, British Museum of Natural History.

FRANZ J. LOEWINSON-LESSING, Leningrad, Russia. Professor of Geology and Mineralogy, Polytechnical Institute.

JOHNANNES WALTHER, Halle-Wittenberg, Germany. Professor of Geology and Paleontology, Vereinigte Friedrichs-Universität.

FELLOWS

ERNEST F. BEAN, B. A., M. A., State Geologist, Wisconsin Geological and Natural History Survey, Madison, Wisconsin.

ARTHUR CHARLES BEVAN, B. S., Ph. D., Assistant Professor of Geology, University of Illinois, Urbana, Illinois.

HALBERT PLEASANT BYBEE, B. S., A. B., Ph. D., Geologist, Dixie Oil Company, San Angelo, Texas.

RALPH W. CHANEY, B. S., Ph. D., Research Associate, Carnegie Institution of Washington, Berkeley, California.

THOMAS HENRY CLARK, A. B., Ph. D., Assistant Professor of Paleontology, McGill University, Montreal, Canada.

GEORGE EVERT CONDRA, B. S., A. M., Ph. D., Director, Conservation and Survey Division, University of Nebraska, Lincoln, Nebraska.

RICHARD MONTGOMERY FIELD, B. S., A. M., Ph. D., Associate Professor of Geology and Curator of Stratigraphy and Historical Geology, Princeton University, Princeton, New Jersey.

HOYT STODDARD GALE, A. B., S. B., Geologist, Los Angeles, California.

HERMAN GUNTER, B. S., State Geologist of Florida, Tallahassee, Florida.

GEORGE MARTIN HALL, A. B., Ph. D., Assistant Geologist, United States Geological Survey; Associate Professor of Geology, University of Tennessee, Knoxville, Tennessee; Assistant Geologist, Maryland Geological Survey.

WINTHROP PERRIN HAYNES, A. B., A. M., Ph. D., Chief Geologist for European interests of Standard Oil Company of New Jersey, Paris, France.

BENJAMIN FRANKLIN HOWELL, B. S., A. M., Ph. D., Associate Professor of Geology and Paleontology, Curator of Invertebrate Paleontology, Princeton University, Princeton, New Jersey.

RUSSELL STAFFORD KNAPPEN, B. S., M. A., Geologist, Gulf Refining Company, Pittsburgh, Pennsylvania.

CLYDE ARNETT MALOTT, A. B., A. M., Ph. D., Professor of Geology, Indiana University, Bloomington, Indiana.

VICTOR ELVERT MONNETT, A. B., Ph. D., Head of Department of Geology and Director of School of Engineering Geology, University of Oklahoma, Norman, Oklahoma.

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NECROLOGY

The Secretary announced the deaths during the year of eight Fellows of the Society and the customary brief oral tributes were then called for, as follows:

William Otis Crosby, by H. W. Shimer and Waldemar Lindgren.
John Burchmore Harrison, by Stanley Smith.
James F. Kemp, by Charles P. Berkey.
William Kennedy, by E. T. Dumble.
Frank Hall Knowlton, by David White.
Willis Thomas Lee, by William C. Alden.
John C. Smock, by Henry B. Kummel.
William Lawrence Uglow, by M. B. Baker.

MEMORIALS

The following memorials are printed in the Proceedings of volume 38:

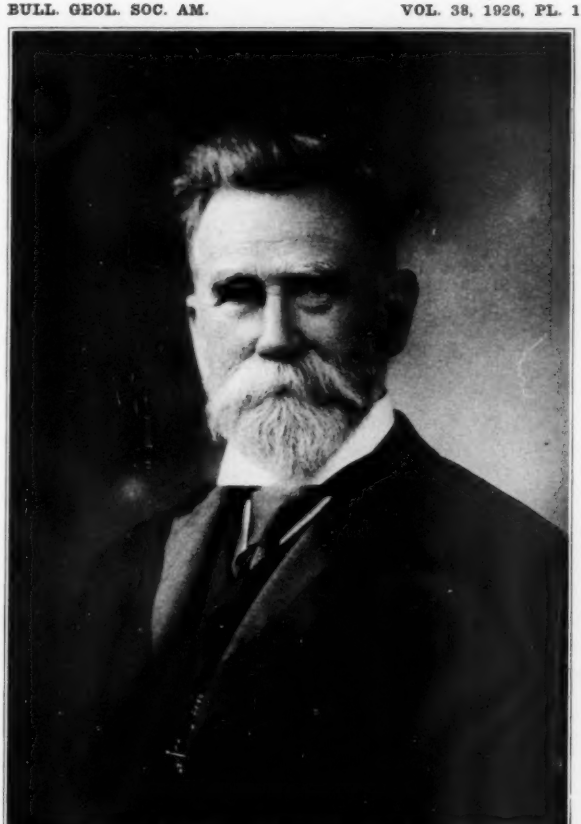
Memorial of Robert Bell, by H. M. Ami.
Memorial of William Otis Crosby, by H. W. Shimer and Waldemar Lindgren.
Memorial of John B. Harrison, by Stanley Smith.
Memorial of Frank Hall Knowlton, by David White.
Memorial of Willis Thomas Lee, by William C. Alden.
Memorial of John C. Smock, by Henry B. Kummel.
Memorial of William Lawrence Uglow, by M. B. Baker.

MEMORIAL OF ROBERT BELL [1]

BY H. M. AMI

In undertaking to write an outline of the life and work of our late Fellow, Dr. Robert Bell, one of the pioneers and explorers in the realm of Canadian geography and geology, the present writer is conscious of the fact that although he was personally acquainted with Dr. Bell for some twenty-five years—twenty years as a colleague in the same office and nearly six years as an official under him—the task is not an easy one.

[1] Manuscript received by the Secretary of the Society May 14, 1926.



Robert Bell

It was on the eighteenth day of June, 1917, that our late Fellow, Dr. Robert Bell, passed away at Rathwell, Manitoba, Canada, in the seventy-seventh year of his life. He had been failing in health for some time.

Robert Bell was born in the township of Toronto, Upper Canada (now Ontario), June 3, 1841. He was of Scottish parentage and lineage. Both his father and his grandfather were clergymen of the Established Church of Scotland. His father was the Reverend Andrew Bell, of L'Orignal, Ontario, some 60 miles below Ottawa City, on the Ottawa River. His grandfather was the Reverend William Bell, of Perth, who came to Canada in 1920. His mother's maiden name was Elizabeth Notman, a member of the Dalhousie family.

From his father young Robert Bell inherited a decided taste for the natural sciences, especially for geology. In the "Geology of Canada" for 1863, Sir William Logan and other members of his staff speak of the Reverend Andrew Bell as a gentleman who had made a systematic collection of rocks and of the fossils of the Paleozoic formations of the lower Ottawa River district. Many of these specimens found their way into the cases and rooms of the museum of the Geological Survey in Montreal and were, up to a few years ago, in the museum of the Geological Survey at Ottawa. The bulk of the collections, however, are still in the museum of Queens University, Kingston.

Those were pioneer days, and very fortunate was the youth, brought up in the manse, whom his father had educated in the County of Prescott Grammar School and who accompanied him in his numerous excursions for rocks and fossils. Thus Robert Bell early in life developed a taste for nature studies. As a boy of fifteen, Bell was attached to a field party of the Geological Survey of Canada. Later he attended lectures in McGill University, Montreal, in the Faculty of Engineering, and later still in the Faculty of Medicine of the same university. He was appointed to the staff of the Geological Survey of Canada in December, 1856.

In 1861 he was graduated with the degree of civil engineer from McGill University, where he won the Governor General's medal. His work in connection with the Geological Survey of Canada, located then in Montreal, must have been carried on concurrently with his studies in the Engineering Faculty at McGill. Later in life he attended lectures and followed the medical courses in McGill for some four years. These courses in medicine and surgery were evidently also taken and followed concurrently with his official geological duties at the Survey. In 1878 he was graduated as doctor of medicine and surgery and became a member of the College of Physicians and Surgeons of Lower Canada.

In 1873 Robert Bell was married to Agnes, daughter of the late Alex-

ander Smith, of Westbourne, Glasgow, and Auchentroig, Sterling, Scotland, by whom he is survived. He had one son, Donald, and three daughters, Alice, Margaret (Mrs. Douglas), and Olga. All survive him except Donald, who died in February, 1924.

During his leisure moments and during his travels Bell managed to carry on researches or studies in chemistry—first under Thomas Sterry Hunt, chemist to the Geological Survey of Canada, and then in Scotland, under Sir Lyon Playfair, Dr. Crum Brown, and also under Professor Dittmar and Professor Fairly. Dr. Bell often spoke of his desire to attend the wants of the natives in the distant parts of the Dominion and used to declare that to be the reason for his medical training in Montreal.

From 1863 to 1867 Bell was on the staff of Queens University, Kingston, Ontario. While his duties at Queens were of an academic nature during the winter months, Bell's services were utilized during the summer by the Geological Survey of Canada. In 1880, when the Geological Survey of Canada moved its headquarters, offices, and museum to Ottawa, he became a resident of Ottawa.

In 1862 Dr. Bell was elected Fellow of the Geological Society of London, England, and in 1882 he was selected as one of the original, or foundation, Fellows of the Royal Society of Canada. He was Representative Fellow in the Corporation of McGill University from 1880 to 1886. In 1883 he was elected Member of the American Institute of Mining and Metallurgy, and in the same year was created a Bachelor of Applied Science in McGill University. The same year he received the honorary degree of Doctor of Laws from Queens University. One of the highest awards that can be given to any man fell to Dr. Bell's lot in 1906, when he received the King's or Patron's gold medal.

An attempt to write the life and work of a man who was one of the pioneer geologists and explorers of British America in the middle of the last century is like unraveling part of a network of facts in the early history of a country. The work of Robert Bell, one of the earliest Fellows elected (1889) to this Society, is intimately associated with the work of the pioneer geologists on the staff of the Geological Survey of Canada, the first Federal Geological Survey established in America under the able leadership of Sir William Edmund Logan. Dr. Bell's first piece of work was as an assistant on the summer field party of James Richardson in the Gaspé Peninsula. He collected objects of natural history along the routes surveyed, on which he specially reported. Again, in 1858, James Richardson, with Robert Bell as assistant, explored the country between Rivière du Loup, Sainte Anne des Monts, and along the coast to the Marsouin River.

Robert Bell was sent along in 1859, as head of the party, with instructions to explore the north shore of Lake Huron in the vicinity of the Manitoulin Islands, where he also collected a fine series of fossils from the Richmond (Neo-Ordovician) and other formations. Returning to Owen Sound, he traced the outcrop of the Silurian formations along the face of the Niagara escarpment as far as Lake Ontario and the Niagara Peninsula. In 1860 he went out into the field as assistant to Alexander Murray, helping him in the explorations west of Sault Sainte Marie, on the shores of Lake Superior. After Murray left for Sarnia, Bell led the party along the north shore to the Bruce Mines, calling at the Manitoulin Islands, as he had done the year previous, and making collections.

In 1861 Bell worked out the distribution of the geological formations westward of the Niagara escarpment in the counties of Grey, Bruce, Huron, Wellington, Waterloo, Perth, Brant, and Haldimand. He also collected specimens for the International Exhibition of 1862, held in London, at which Canada's geological resources (materials of economic value in its crust) were well represented, so far as the field of activities of the Geological Survey lay under the able direction of Sir William Logan. The following year he returned to Gaspé and made track surveys of the Dartmouth, York, Malbay, and Grand rivers, and also made extensive collections of fossils at Port Daniel and Gaspé Bay.

The summer of 1863 Bell spent in the Province of Quebec, accompanying James Richardson in a study of the complex problems in that critical region of Canadian geology. On returning to Montreal after the field season was over, Bell received the offer of "Interim Professor of Chemistry and Natural History," an appointment on the teaching staff of Queens University, where his father, the Reverend Andrew Bell, had resided.

In 1869 he resigned this position, finding that it interfered with his own work. Further connection with Queens University may be found in the record that "at the April convocation, 1883, the honorary degree of Doctor of Laws was conferred upon Dr. Bell."

The summer of 1865 saw Robert Bell again employed by the Geological Survey of Canada in an exploration of Grand Manitoulin Island, when he was accompanied by H. G. Vennor.

During the season of 1870 to 1871 Dr. Bell worked north of Lake Superior. The exploration extended over an area measuring about 200 miles each way.

In 1872 to 1873 Alfred R. C. Selwyn, Director of the Survey, devoted a portion of that season to a preliminary exploration westward from Lake Superior to Fort Garry, in which he was accompanied and assisted by

Robert Bell. In the 1873 to 1874 Summary Report of the Geological Survey of Canada, record is made of the explorations made by Dr. Bell along the valley of the Qu'Appelle River westward to the elbow of the South Saskatchewan.

In 1876 Dr. Bell made a minute examination of a portion of the eastern shores of Lake Superior west of the Michipicoten River. A portion of the valley of Garden River and the country around Echo Lake were likewise examined, as well as the vicinity of She-ba-o-na-ning and the whole of the northeast shore of Georgian Bay. A partial examination was also made of the country between Parry Sound and Lake Nipissing and a reconnaissance of the region between the latter and the Ottawa River.

During the summer of 1876 Dr. Bell spent some time in Philadelphia in connection with Canadian geological exhibits at the Centennial Exposition.

In 1878 Dr. Bell went from Norway House to Fort York and made surveys of these routes via Oxford and Knee lakes, and Hill, Steel, and Hayes rivers. The following year he, assisted by A. S. Cochrane, completed and extended the work of the previous season in the region north and northwest of Lake Winnipeg. Track surveys and geographical examinations which were made extended over a total distance of 1,700 miles. The Nelson River basin, Lake Winnipeg, the Churchill River, and Hudson Bay were included in this season's work of exploration. His report contains information of special interest with reference to the question of the navigability of the bay and straits and of the proposal to construct a railway from Manitoba to Fort Churchill.

In 1880 he was elected an honorary member of the Geographical Society of Quebec.

During 1881 Dr. Bell carried on explorations and surveys again in the Hudson Bay basin and in the Lake Superior region. In 1882 he proceeded to the Athabasca-MacKenzie region to examine that portion of the Athabasca River not hitherto surveyed, between the confluence of Lake La Bèche River and Clearwater River, and the region south of Athabasca Lake lying between the Athabasca River and the 108th degree of longitude. On this work Dr. Bell ascertained the age of the petroleum-saturated sandstones to be of Cretaceous age and of importance. Dr. Bell held that the source of this petroleum was from the Devonian limestones underlying the Cretaceous beds. In this exploration he was assisted by A. C. Lawson, President of the Geological Society of America, 1925-1926.

During 1883 and 1884 Dr. Bell had continued work on the geology of the district of Keewatin east of lake Winnipeg, in the Lake of the Woods region, with A. C. Lawson and James W. Tyrrell as assistants. Dr. Bell

made a number of track surveys and recognized beds of Huronian age in the Lake of the Woods region.

He became a member of the American Institute of Mining Engineers, 1883, and was given the degree of L.L. D. of Queens University in the same year.

In 1884 Dr. Bell was on the staff of the *Neptune*, with Commander Gordon, exploring Hudson Bay. In 1885 he again explored Hudson Bay on the steamship *Alert*. He intended to return to Ottawa by an overland route, selecting the Severn River Valley as the best under the circumstances for a canoe voyage to the Canadian Pacific Railway. However, the lateness of the season led the Commander to return by the Straits without leaving Dr. Bell ashore at the Severn River. Dr. Bell took advantage of the return journey to examine more of the east coast of the bay and portions of the Hudson Strait.

He was elected honorary member of the Medico-Chirurgical Société of Montreal in 1885 and of the sister society of that same name in Ottawa in 1887.

In 1887 Dr. Bell continued the investigations and survey commenced the summer 1886, between the Montreal River and the northern shore of Lake Huron, with a view of further elucidating the geological structure of the Huronian system as developed in that region, especially in connection with the copper, nickel, argentiferous galena, iron ores, gold-bearing quartz veins, and other economic minerals which characterize this system.

He served as a member of the Royal Commission on the Mineral Resources of Ontario, 1888-89.

Between 1888 and 1892 Dr. Bell mapped the Sudbury and French River sheets in Ontario. In this work he was assisted by a group of young men destined later to make notable contributions to Canadian geology: A. E. Barlow, W. G. Miller, R. W. Brock, T. L. Walker, and H. G. Skill. Bell River was surveyed by him in 1891 and was officially named after him.

Dr. Bell accompanied an exhibition of Canadian minerals to the World's Fair, Chicago, in 1893, and also continued his geological explorations along the north shore of Lake Huron, this work being continued in 1894.

In the Summary Report for the year 1895, the Director, G. M. Dawson, states:

"Dr. Bell successfully descended and surveyed the whole length of the river, which proved to be the main branch of the Nottaway or Noddaway, discharging into the Rupert Bay."

Bell's work during the following summer, 1896, is likewise recorded:

"The basin of the Nottaway or Noddaway River, one of the largest rivers flowing to James Bay, has been further explored during the past season by Dr. Bell, and with results of interest both geographically and geologically. Thirteen branches of the main stream were surveyed for portions of their lengths and a route was explored northward from Waswanipi L. to Nemiskan Lake, an expansion of Rupert R., by means of various streams and lakes. The more important geological results obtained are those relating to the distribution of the Huronian rocks in the region, which it will now be possible to lay down with some accuracy on the map."

In the year 1897 Dr. Bell was in charge of exploratory work north of Hudson Strait, made possible by the cooperation of the Department of Marine and Fisheries in connection with the Hudson Bay Expedition under Dr. Wakeham. The coast explored by Dr. Bell extended from Ashe Inlet and Big Island and northwestward to Tchorback, a length of 250 miles, and a journey was also made by him inland from the head of Amadjuak Fiord to the vicinity of Amadjuak Lake, a distance estimated at 50 miles.

The next summer Dr. Bell spent in the Michipicoten region, on the northeast coast of Lake Superior, where he devoted his energies to defining the boundaries and character of the Huronian rocks to be found in the district; also, to newly made discoveries of gold in what has become known as the Wawa area. Thence a survey of the whole of the course of the White River was made and an exploration of the country about its source.

In the spring of 1899 Dr. Bell was directed to explore Great Slave Lake, to which region a number of prospectors had found their way in 1897 and 1898 and from which many specimens of lead and copper ores had been brought out. According to the Director, "The discovery of gold in payable quantities had also been reported, and especial interest in the region was being shown by the people of Edmonton and other adjacent parts of the Northwest."

The following summer Dr. Bell returned to Michipicoten district, north of Lake Superior, as a result of a recent discovery of the extensive body of iron ore on which was afterwards located the Helen mine.

Among other accomplishments not indicated in the sketch, Dr. Bell is known to have discovered axinite on Hudson Bay, graphite and mica in Hudson Strait. He represented the Royal Society of Canada at the International Geological Congress in Vienna (1903). He also sat with the International Committee on Geological Nomenclature with a group of Canadian and United States geologists in respect to the more ancient

and crystalline rocks of the earth's crust. Dr. Bell described the *Manitournuk* group of Labrador (west coast) and discussed the problem as to the elevation of the Hudson Bay shores in recent times.

On the death of Dr. George M. Dawson, in 1900, Dr. Bell became Acting Director of the Geological Survey of Canada and remained in this position until 1906, a period marked by important growth of the mining industry and changing demands on the institution in his charge.

Most of Dr. Bell's reports were published by the Geological Survey of Canada and bear witness to the thoroughness of his researches, while many papers on various questions were contributed by him to various societies and journals.

Dr. Bell was appointed to the Geographic Board of Canada in January, 1900. He was a Fellow of the Royal Geographical Society of London.

He received the Kings or Patrons Royal Geographical Medal of the Royal Geographical Society of London in 1906 and the Cullum Medal of the American Geographical Society in the same year.

He was awarded the Edward VII Imperial Service Order, given for distinguished service in any branch of the Empire.

A biographical sketch of the work of Dr. Bell appeared in the Bulletin of the Canadian Mining Institute for October, 1917, by Prof. F. D. Adams, who in the early days of his geological career was one of his assistants; also, there appeared from Charles Hallock's pen, in "Forest and Stream," volume 53, number 41, July, 1899, an article on "One of Canada's Explorers." This article was reproduced in pamphlet form in Washington, D. C., February, 1901, and "Dedicated to the National Geographic Society of Washington, D. C." The object of this pamphlet, according to the author, "is to set before the geographic societies of the old and new worlds the comprehensive work which has been accomplished during the past forty-five years by the indefatigable subject of this sketch, whose innate modesty has hitherto kept him from exploiting his own remarkable achievements, which cover well-nigh one-half of this northern continent. *Fiat justicia.*"

This fifteen-page pamphlet relates in glowing terms the achievements of Dr. Bell during the forty-five years of his work in Canada as an explorer. Details of pioneer geological and geographical work are given by Mr. Hallock, which accord Dr. Bell an amount of work which almost surpasses credence.

"He had visited (the narrator says) every square mile of the several islands of the Manitoulin Chain before any township surveys had been made or a single settler had gone there. . . . While making his extraordinary record of geological and topographical survey and exploration, Dr. Bell has had more

adventures and thrilling experiences and more discomforts, lack of provisions, etcetera, and has seen more of the game and fish, the real wild Indians and Eskimos, and the Hudsons Bay Company's people of all ranks than any other white man or any Indian that ever lived. . . . He (Dr. Bell) has a rare genius for telling his experiences, and although he has never written them out from his field-notes, the original records in his possession would fill many most entertaining and useful volumes."

According to *Nature* (London), July 5, 1917, page 370,

"Dr. Bell's most important work was the exploration and mapping of both sides of Hudson Bay and the strait, and of the rivers entering Hudson Bay from the south. He also conducted the first surveys of Great Slave Lake, Lake Nipigon, and several other inland waters. As a geologist, he paid special attention to the oldest rocks of the Laurentian and Huronian periods, but also made valuable contributions to our knowledge of the Pleistocene deposits of Canada. As a naturalist, he was a keen and skilled observer in many directions, but was especially interested in forestry. He prepared a map showing the northern limits of trees in Canada."

Dr. Lawson, in an interesting article entitled "Out of Beaten Paths," published in the *University of California Chronicle* for January, 1926, pages 61 and 62, makes the following interesting statement with reference to his first exploring expedition as assistant to Dr. Bell:

"It was my good fortune to see something of the northwest of Canada just at the time when the gates to it were being opened, and before the great migration had reached beyond the new Province of Manitoba. In the summer of 1882 I accompanied Robert Bell, of the Geological Survey of Canada, as his assistant, on an excursion across the prairies to the waters of the Athabasca. It was a very simple sort of an expedition. We had two buckboards and two horses. Bell drove one and I the other. The country that we traversed was a wilderness full of charm and wonder to an untraveled youngster like myself, in his third year in college. We journeyed for days and even weeks without seeing a habitation, and the only people met with in a thousand miles were those at the Hudsons Bay Company's posts, or an occasional pioneer making his lonely way from one post to another. A vast solitude possessed the landscape, which, though ever shifting, was ever the same—an endless rolling surface of waving grass and myriads of flowers beneath a bright blue sky, with drifting snow-white clouds. Here and there the poplar bluffs and the gleam of saline waters in small lakes accentuated the glorious monotony of the prairie."

Dr. Bell deserves great credit for his determination as a boy, and later as a man, to improve his mind and increase his store of knowledge in college and in the university. He seems to have sought after knowledge persistently, from whatever source he could obtain it, whether from lecture courses given in the university (McGill) in Montreal, while he was on the staff of the Geological Survey, or from men who returned from

their explorations and surveys in different portions of Canada, especially in the northern parts, such as Labrador, the Arctic regions, and the far northwest. He had wonderful powers of assimilating and coordinating new facts. As a writer, his style was easy and his powers of description varied. Many of his contributions to our knowledge of the geology of Canada, especially eastern Canada, deal with natural-history subjects, including the plants, fresh-water and other shells of the country. Many of his reports to the government, and scientific papers embodied in Canadian as well as other publications, cover a vast amount of ground, being of a reconnaissance or preliminary type. Bell was especially fond of investigating and exploring regions hitherto untraversed. Pioneer work of this nature can scarcely be appreciated today, when newer and more up-to-date methods of examining a hitherto-unknown territory are employed. A glance over the bibliography or list of writings of Robert Bell shows the extent of his explorations and surveys in the earlier days of his life, while his later years in office were devoted to administrative work. In manner he was kindly and engaging, as testified by the wide circle of his friends and acquaintances.

He was much interested in astronomy, but his greatest interest beyond his work was in folklore and forestry. Throughout his travels, he was constantly on the lookout for contributions in the way of folklore of North America. The Indians were appreciative of his interest and made him honorary chief of the Algonkians at Grand Lake.

Dr. Bell retired from director of the Geological Survey in 1906, and from then until his death in June, 1917, at Rathwell, Manitoba, he devoted himself to travel and private scientific investigation.

The following is a list of the geological writings or publications by Robert Bell:

Bibliography

Report for the year 1857. Canada Geological Survey, Report of Progress, 1857, Montreal, 1858, pages 95-108.

On the natural history of the Gulf of Saint Lawrence and the distribution of the Mollusca of eastern Canada. Canadian Naturalist, volume 4, 1859, pages 197-220, 241-251.

On the occurrences of fresh-water shells in some of our post-Tertiary deposits. Canadian Naturalist, volume 6, 1861, pages 42-51.

List of recent land and fresh-water shells collected around Lakes Superior and Huron in 1859-1860. Canadian Naturalist, volume 6, 1861, pages 268-270.

Catalogue of birds collected and observed around Lakes Superior and Huron in 1860. Canadian Naturalist, volume 6, 1861, pages 270-275.

On the superficial geology of the Gaspé Peninsula. Canadian Naturalist, volume 8, 1863, pages 175-183.

Roofing slate as a source of wealth to Canada. Canadian Naturalist, volume 8, 1863, pages 358-369.

Rapport sur les Iles Manitoulines. Exploration Géologique du Canada, Report of Progress, 1863-1866, pages 171-186, 1886. (Translation.)

Report on the Manitoulin Islands. Canada Geological Survey, Report of Progress, 1863-1866. Ottawa, 1866, pages 165-179.

Report on the geology of the northwest side of Lake Superior and of the Nipigon district. Canada Geological Survey, Annual Report, 1867-1869, pages 313-364, 345-349, three folded maps (in pocket), 1870.

The Nipigon territory. Canadian Naturalist, series II, volume 5, 1870, pages 118-120.

Report on the geology of the Grand Manitoulin, Cockburn, Drummond, and Saint Joseph's Islands. Canada Geological Survey, Report of Progress, 1866-1869, pages 109-116, map, 1870.

And Alfred Bell: The English crags and their stratigraphical divisions indicated by their invertebrate fauna. Geological Magazine, London, volume 8, 1871, pages 256-263.

Report on the country between Lake Superior and the Albany River. Canada Geological Survey, Report of Progress, 1871-1872, pages 101-114, Montreal, 1872.

Report on the country north of Lake Superior between the Nipigon and Michipicoten rivers. Canada Geological Survey, Report of Progress, 1870-1871, pages 322-351, 1872.

Report on the country between Lake Superior and Lake Winnipeg. Canada Geological Survey, Report of Progress, 1872-1873, pages 87-111, Montreal, 1873.

The mineral region of Lake Superior (abstract). [Read to Montreal Natural History Society, 1873.] American Journal of Science, third series, volume 6, 1873, pages 224-225.

The mineral region of Lake Superior. Abstract, Canadian Naturalist, new series, volume 7, 1875, pages 49-51; American Journal of Science, third series, volume 6, 1875, pages 224-225.

Report on the country between Red River and the South Saskatchewan, with notes on the geology of the region between Lake Superior and Red River. Canada Geological Survey, Report of Progress, 1873-1874, pages 66-93, 1874. Abstract, American Journal of Science, third series, volume 9, 1875, page 312.

On the Huronian and mineral-bearing rocks of Lake Superior. [Read to Montreal Natural History Society.] Canadian Naturalist, new series, volume 7, 1875, pages 49-51.

Report on the country west of Lakes Manitoba and Winnipegosis, with notes on the geology of Lake Winnipeg. Canada Geological Survey, Report of Progress, 1874-1875, pages 24-56, 1876. Abstract, American Journal of Science, third series, volume 13, 1876, page 218 (one-fourth page).

Sketch of the geology of Ontario and Quebec. In Walling Tackabury's Atlas of the Dominion of Canada, 1876, pages 11-17.

Report of an exploration in 1875 between James Bay and Lakes Superior and Huron. Canada Geological Survey, Report of Progress, 1875-1876, pages 294-342, 1877.

Report on geological researches north of Lake Huron and east of Lake Superior. Canada Geological Survey, Report of Progress, 1876-1877, pages 195-220, 1878.

Sketch of the geology of the route of the Intercolonial Railway. Canadian Journal, new series, volume 15, 1878, pages 381-387.

Report on an exploration of the east coast of Hudson Bay, 1877. Canada Geological Survey, Report of Progress, 1877-1878, pages 1C-37C, Montreal, 1879. Abstract, American Journal of Science, third series, volume 18, 1879, page 483, map in atlas.

Report on explorations on the Churchill and Nelson rivers and around God's and Island lakes, 1879. Canada Geological Survey, Report of Progress, 1878-1879, pages 1C-44C, plates, folded map, 1880.

Report on the country between Lake Winnipeg and Hudson Bay. Canada Geological Survey, Report of Progress, 1877-1878, pages 1CC-31CC, map in atlas, Montreal, 1879. Abstract, American Naturalist, volume 14, 1880, pages 42-43.

On the commercial importance of Hudson Bay, with remarks on recent surveys and investigation. Royal Geographical Society Proceedings, new series, volume 3, number 10, October, 1881, pages 577-586, map.

Report on Hudson Bay and some of the lakes and rivers lying to the west of it. Canada Geological Survey, Report of Progress, 1879-1880, pages 1C-56C, Montreal, 1881. Abstract, Philosophical Magazine (London, Edinburgh, and Dublin), new series, volume 14, 1882, page 70.

The geographical distribution of the forest trees of Canada. Canada Geological Survey, Report of Progress, 1879-1880, pages 38C-56C, 1882, map.

Reports on the geology of the basin of Moose River and of the Lake of the Woods and adjacent country. Canada Geological Survey, Report of Progress, 1880-1882, pages 1C-9C, map, Montreal, 1883.

On the geology of the Lake of the Woods and adjacent country. Canada Geological Survey, Report of Progress, 1880-1882, pages 11C-28C, map, Montreal, 1883.

Notes on the birds of Hudson Bay. Proceedings and Transactions of the Royal Society of Canada, volume 1, section IV, 1883, pages 49-54.

The causes of the fertility of the land in the Canadian Northwest Territories. Proceedings and Transactions of the Royal Society of Canada, volume 4, section IV, 1883, pages 157-162. Abstract, Canadian Record of Natural History, volume 1, 1884, pages 14-15.

The geology and economic minerals of Hudson Bay and northern Canada [read May 23, 1884]. Transactions of the Royal Society of Canada, volume 2, section IV, 1885, pages 241-245. Abstract, Science, volume 3, June 20, 1884, pages 755-756.

On the occurrence of petroleum in the Northwest Territories, with notes on new localities. Proceedings of the Canadian Institute, new series, volume 1, 1884, pages 225-230.

Report on part of the basin of the Athabasca River, Northwest Territory. Canada Geological Survey, Report of Progress, 1882-1884, pages 5CC-35CC, map, Montreal, 1885. Abstract, Science, volume 6, 1885, page 522.

Report on geology of northern shore of Labrador. Report of Hudson Bay Expedition under Lieutenant A. R. Gordon, 1884. Abstract, American Naturalist, volume 19, 1885, pages 832-833.

Observations on the geology, zoology, and botany of Hudson Strait and Bay, made in 1885. Canada Geological and Natural History Survey, Annual Report, 1885, page 27DD, two plates, folded map, 1885.

The topography and geology of the Hudson Bay region. Science, volume 5, 1885, pages 256-257.

Observations on the geology, mineralogy, zoology, and botany of the Labrador coast, Hudson Strait and Bay. Canada Geological Survey, Report of Progress, 1882-1884, pages 1DD-37DD, Montreal, 1885. Abstracts, Science, volume 6, 1885, page 522; American Journal of Science, third series, volume 30, September, 1885, page 242.

List and notes of mammals of the vicinity of Hudson Bay and Labrador. Canada Geological Survey, Report of Progress, 1882-1884, Report DD, Appendix II, 1885, pages 48DD-53DD.

List and notes of birds of the vicinity of Hudson Bay and Labrador. Canada Geological Survey, Report of Progress, 1882-1884, Report DD, Appendix III, 1885, pages 54DD-56DD.

The mode of occurrence of apatite in Canada. Engineering and Mining Journal, volume 39, May 9, 1885, page 316.

The mode of occurrence of apatite in Canada. Proceedings of the Canadian Institute, third series, volume 3, 1886, pages 294-302.

The mineral resources of the Hudson Bay Territories. Transactions of the American Institute of Mining Engineers, volume 14, 1886, pages 690-698, map.

Observations on the geology, zoology and botany of Hudson Bay and Strait. Canada Geological Survey, Annual Report, volume 1, new series DD, 1886, 26 pages, Montreal, 1886. Abstract, Geological Magazine, decade III, volume 4, 1886, pages 179-180.

The forests of Canada. Canadian Record of Science, volume II, number 2, 1886, pages 65-77, map.

Metallic ores of the country between the Great Lakes and Hudson Bay. Engineering and Mining Journal, volume 42, December 26, 1886, page 458.

Marble Island and the northwest coast of Hudson Bay. Proceedings of the Canadian Institute, third series, volume 4, 1887, pages 192-204, 2 plates. Abstract, Scottish Geographical Magazine, volume 3, 1887, page 321.

On some points in reference to ice phenomena. Transactions of the Royal Society of Canada, volume 4, section III, 1887, pages 85-91.

Rock specimens from Cumberland Sound, Baffin Land. Science, volume 10, 1887, page 287.

The silver mines of Thunder Bay, Lake Superior. Engineering and Mining Journal, volume 43, 1887 pages 23, 42.

Report on Great Manitoulin Island. Canada Geological and Natural History Survey, Annual Report, 1886, new series, volume 2, 1887, pages 22A-26A.

Report on an exploration of portions of the At-ta-wa-pish-kat and Albany rivers, Lonely Lake to James Bay. Canada Geological and Natural History Survey, Annual Report, 1886, new series, volume 2, 1887, pages 1G-38G, 4 plates. Abstract, Geological Magazine, decade 3, volume 6, 1889, page 134.

List of Lepidoptera collected in the southern part of Keewatin district. Canada Geological and Natural History Survey, Annual Report, 1886, new series, volume 2, Appendix, 1887, page 39G.

On views on the Archæan. International Congress of Geology, American Committee, Reports, 1888, page A, 1888. American Geologist, volume 2, 1888, pages 146-184, in part.

The petroleum field of Ontario. Transactions of the Royal Society of Canada, volume 5, section IV, 1888, pages 101-113.

On the Chickaree, or red squirrel (*Sciurus hudsonius* Pennant). [Appendix.] Transactions of the Royal Society of Canada, volume 5, section IV, 1888, pages 186-188.

Summary of exploration in 1887 about the Lakes Temiscaming and Abittibi, the Montreal River, and the upper waters of the Ottawa. Canada Geological Survey, Annual Report, 1887-1888, new series, volume 3, part 1, Report A, Montreal, 1889, pages 22-27.

Summary of observations between the Montreal River and the northern shores of Lake Huron. Canada Geological Survey, Reports, new series, volume 3, part 1, Report A, Montreal, 1889, pages 77-80.

The origin of some geographical features in Canada. Canadian Record of Science, volume 3, 1888, pages 163-165. Abstract, Popular Science Monthly, volume 35, 1889, pages 422-423.

The geology of Ontario, with special reference to economic minerals. Royal Commission on Mineral Resources of Ontario, Report, 57 pages, Toronto, 1889. Abstracts, American Geologist, volume 5, 1889, pages 238-240; Engineering and Mining Journal, volume 49, 1889, page 468.

Presidential address: The Huronian system in Canada. Transactions of the Royal Society of Canada, volume 6, section IV, 1889, pages 3-13. Abstract, American Geologist, volume 2, 1889, page 361.

On glacial phenomena in Canada. Bulletin of the Geological Society of America, volume 1, 1890, pages 287-310. Abstract, American Naturalist, volume 24, 1890, pages 207-208, 771.

The origin of gneiss and some other primitive rocks. Abstract, Proceedings of the American Association for the Advancement of Science, volume 38, 1890, pages 227-231.

Summary report on surveys in the Sudbury district. Canada Geological Survey, Reports, 1888-1889, new series, volume 4, Report A, Montreal, 1890, pages 29-32.

The nickel and copper deposits of Sudbury district, Canada. Bulletin of the Geological Society of America, volume 2, 1891, pages 125-137. Abstract, Engineering and Mining Journal, volume 51, 1891, page 328.

Summary report of work in the Sudbury region, Ontario. Canada Geological Survey, Summary Report, 1890; Annual Report, volume 5, 1891, pages 41A-43A.

Alexander Murray: Canadian Record of Science, volume 5, 1892, pages 77-96, portfolio.

Report on field-work in area south of the Sudbury district, Ontario. Canada Geological Survey, Summary Report, 1891; Annual Report, volume 5, 1892, pages 31A-35A.

Report on the Sudbury mining district, with an appendix by Prof. George H. Williams. Canada Geological Survey, Reports, new series, volume V, part 1, 1890-1891; Report F, 91 pages, 1893. Abstract, American Geologist, volume IX, 1892, pages 269-270.

The succession of the glacial deposits of Canada. Abstract, American Geologist, volume 12, 1893, pages 226-227.

Summary report of field-work on the Byng Inlet sheet, Ontario. Canada Geological Survey, Summary Report, 1892, Annual Report, volume 6, 1893, pages 30A-34A.

The contact of the Laurentian and Huronian north of Lake Huron. Abstract, American Geologist, volume 11, 1893, pages 135-136.

Postglacial outlet to the Great Lakes. Bulletin of the Geological Society of America, volume 4, 1893, pages 425-427.

Pre-Paleozoic decay of crystalline rocks north of Lake Huron. Bulletin of the Geological Society of America, volume 5, 1894, pages 357-366, plates 15-16. Abstract, American Geologist, volume XIII, 1894, page 214.

Summary report on field-work north of Lake Huron. Canada Geological Survey, Summary Report, 1893; Annual Report, volume 6, 1894, pages A33-A39.

On the occurrence of lignite and anthracite around Hudson Bay. Canadian Mining Review, volume 14, 1895, pages 8-10.

Honeycombed limestones in Lake Huron. Bulletin of the Geological Society of America, volume 6, 1895, pages 297-304, plates 13-15. Abstract, Science, new series, volume 1, 1895, page 67.

Report on field-work in the Lake Huron region. Canada Geological Survey, Summary Report, 1894; Annual Report, volume 7, 1895, pages 52A-55A.

A great preglacial river in northern Canada. Abstract, American Geologist, volume 16, 1895, page 132.

Proofs of the rising of the land around Hudson Bay. American Journal of Science, fourth series, volume 1, 1896, pages 219-228. Abstracts, American Geologist, volume 17, 1896, page 99; Science, new series, volume 3, 1896, page 53.

Observations on Baffinland. Abstract, American Journal of Science, fourth series, volume 4, 1897, pages 476-477.

Recent explorations to the south of Hudson Bay. Geographical Journal, volume 10, 1897, pages 1-17, map.

Evidence of northeasterly differential rising of the land along Bell River, Canada. Bulletin of the Geological Society of America, volume 8, 1897, pages 241-250, plates 23-24.

Report of an exploration of the Nottaway River. Canada Geological Survey, Summary Report, 1895; Annual Report, volume 8, 1896, pages 75A-85A; Annual Report, volume 9, 1897, pages 64A-74A.

Report on the geology of the French River sheet, Ontario. Canada Geological Survey, Annual Report, new series, volume IX, Report I, 1898, 29 pages, map.

On the occurrence of mammoth and mastodon remains around Hudson Bay. Bulletin of the Geological Society of America, volume 9, 1898, pages 369-390, one figure. Abstract, Science, new series, volume 7, 1898, page 80.

Report of explorations in Hudson Strait region. Canada Geological Survey, Summary Report, 1897; Annual Report, volume 10, 1898, page 75A-83A.

Fossil-like forms in the Sault Ste. Marie sandstone. Abstract, Science, new series, volume VII, 1898, page 80.

Rising of land around Hudson Bay. Smithsonian Institute, Annual Report for 1897, pages 359-367, 1898.

Outline of geology of Hudson Bay and Strait. Abstracts, Science, new series, volume IX, 1899, pages 101-102; American Geologist, volume 23, 1899, pages 92-93; Ottawa Naturalist, volume 12, 1899, page 195.

The geological history of Lake Superior. Transactions of the Canadian Institute, volume VI, 1899, pages 45-60, two figures.

Report of an examination of the Michipicoten district, Ontario. Canada Geological Survey, Summary Report, 1898; Annual Report, volume 11, 1899, pages 99A-106A.

Report on explorations in the Great Slave Lake region, Mackenzie district. Canada Geological Survey, Summary Report, 1899; Annual Report, volume 12, 1900, pages 103A-110A.

Report of an exploration on the northern side of Hudson Strait. Canada Geological Survey, Annual Report, volume XI, 1901, 38 pages, four plates (including frontispiece), folded map.

Laurentian limestones of Baffinland. Abstracts, Bulletin of the Geological Society of America, volume 12, 1901 page 471; Science, new series, volume 13, 1901, page 100; Canadian Record of Science, volume 8, 1902, pages 472-473.

Report on the geology of the basin of the Nottaway River, with a map of the region. Canada Geological Survey, Annual Report, 1900, volume 13, 1902, pages 1K-11K, frontispiece (folded colored map).

Summary report on the operations of the Geological Survey of Canada for the year 1901. Canada Geological Survey, Summary Report for 1901; Annual Report, volume 14, 1902, 269 pages, maps, numbers 751-764.

Summary report on the operations of the Geological Survey of Canada for the calendar year 1902. Canada Geological Survey, Summary Report for 1902; Annual Report, volume 15, 1903, 472 pages. Abstract, Science, new series, volume 17, 1903, pages 299-300.

Volcanic origin of natural gas and petroleum. Journal of the Canadian Mining Institute, volume 6, 1904, pages 126-128.

Summary report on the operations of the Geological Survey of Canada for the calendar year 1903. Canada Geological Survey, Summary Report for 1903; Annual Report, volume 15, 1904, 212 pages, maps.

The advantages of combining topographical with geological surveying in unexplored regions. Abstract, Journal of the Canadian Mining Institute, volume 8, 1905, pages 56-58.

Precambrian nomenclature. Ontario Bureau of Mines, Report for 1905, volume 14, part 1, 1905, pages 269-277.

Summary report of the Geological Survey of Canada for the calendar year 1904. Canada Geological Survey, Report for 1904; Annual Report, volume 16, 1905, pages i-xxxviii, 1A-392A, maps.

Summary report of the Geological Survey Department of Canada for the calendar year 1905, 144 pages, 2 maps, 3 plates. Ottawa, 1906.

Report on the Cobalt mining district. Canada Geological Survey, Summary Report for 1905, pages 94-104, 3 plates, 1906; Canadian Mining Review, volume 27, number 4, October, 1906, pages 116-124.

Cobalt district and northward. Canada Geological Survey, Summary Report, for 1906, pages 110-112, 1906.

The occurrence of diamonds in the drift of some of the northern states. Engineering and Mining Journal, volume 82, November 3, 1906, page 819; Journal of the Canadian Mining Institute, volume 9, 1906, pages 124-127.

The Cobalt mining district. Canadian Mining Journal, volume 28, number 10, new series, volume 1, number 8, July 1, 1907, pages 246-248.

Tar sands of the Athabasca River. Bulletin of the American Institute of Mining Engineers, number 17, 1908, pages 157-169, 2 plates; Transactions, volume 38, 1908, pages 836-848, 2 plates. Abstract, Mining World, volume 28, May 9, 1908, page 753.

Personal reminiscenses of Sir William E. Logan. Abstract, Bulletin of the Geological Society of America, volume 18, 1908, page 622.

The diversion of the Montreal River. Abstract, Science, new series, volume 32, August 5, 1910, page 187; Bulletin of the Geological Society of America, volume 21, number 4, 1910, pages 762-763.

The Klondike gold district in the Yukon Valley, Canada. Report of the Australasian Association for the Advancement of Science, twelfth meeting, Brisbane, 1909, pages 282-296, 1910.

The Canadian porcupine, *Erethizon dorsatum* (F. Cuvier). Transactions of the Royal Society of Canada, third series, volume 3, section IV, 1910, pages 29-39.

Memoir of Thomas Chesmer Weston, 1832-1910. Bulletin of the Geological Society of America, volume 22, number 1, March, 1911, pages 32-36, 1 plate (portrait).

MEMORIAL OF WILLIAM OTIS CROSBY [1]

BY H. W. SHIMER AND WALDEMAR LINDGREN

William Otis Crosby was for 54 years connected more or less intimately with the Massachusetts Institute of Technology. Entering as a student in 1871, he became a teacher in the Department of Geology in 1876, and thus continued, rising to become head of the department, until increasing deafness necessitated his retirement in 1907.

He was born in the village of Decatur, in southern Ohio, January 14,

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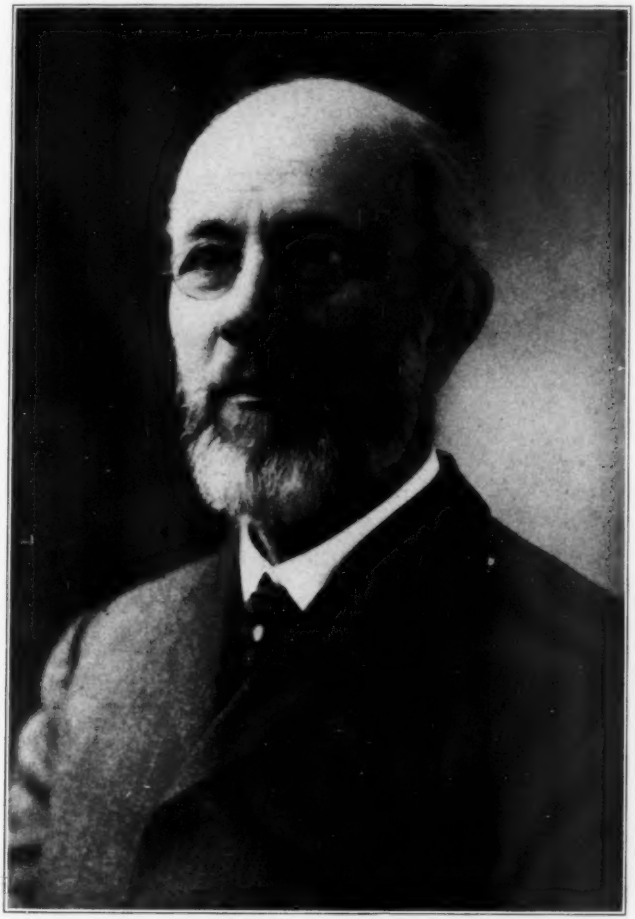


W. O. Crosby

1850. His father, Francis William Crosby, was born in Schenectady, New York, in 1823, and his mother, Hannah Everett Ballard, in Franklin, Vermont, in 1824. The Crosby ancestry goes back in this country to Simon Crosby, who came from England in 1635 and settled in Cambridge, Massachusetts. The first Ballard ancestor in America was William, coming over in 1636.

At the time of Otis's birth his father had settled down as a school teacher. He was a man of rare, strong character and possessed deep anti-slavery convictions, because of which he assisted in the work of the "Underground Railroad," helping fugitive slaves to find their way toward Canada. In 1855 he moved to Toledo, Iowa. Very soon after the outbreak of the Civil War he joined the armies of the North for the defense of the Union and the freeing of the slaves, though in so doing he burdened with heavy responsibilities his wife and son, Otis, for there were now three younger children. When peace was restored he became superintendent of a gold mine in North Carolina. Under these conditions Otis became much interested in nature and began to read books on geology. When later, as clerk in the Pension Bureau at Washington, he had access to a wide range of geological literature, he spent so much of the night in study that after two years he was forced by ill health to return to the outdoor life in North Carolina.

Early in 1871 Crosby accompanied his father to Georgetown, Colorado, where the father had acquired a small silver mill. Here during this summer he guided a party of twenty students and four professors, including President Runkle, from the Massachusetts Institute of Technology about the various mines and up Grays Peak. While piloting this party Crosby's ambition to become a student at Massachusetts Institute of Technology was aroused and he inquired eagerly about its courses and requirements.

It thus came about that Crosby entered Massachusetts Institute of Technology in the fall of 1871. The succeeding year he worked with his father at Georgetown to earn the means to continue his studies. He returned East early in the summer of 1873 to study under Agassiz in the summer school on the Island of Penikese. This was a stimulating experience and gave an additional impulse to his inclination for original research. He reentered Massachusetts Institute of Technology that fall and graduated with the S. B. degree in 1876. The fall following his graduation he was made an assistant in the Department of Geology. In time he became full professor and head of the department. A slight deafness increased until it caused his retirement from teaching in 1907. This retirement gave him more time for work as an engineering geologist, and

he seldom returned from one of his numerous trips without bringing back a collection of rocks, fossils, or ores to enrich the Institute's collections.

In 1876 Crosby married Miss Alice Ballard, of Lansing, Michigan. This proved an ideally happy and mutually helpful union. The very sympathetic home conditions made possible the great amount of work he accomplished. From 1878 their home was in Jamaica Plain, one of the suburbs of Boston.

On December 28 Professor Crosby developed pneumonia, which resulted in his death four days later, December 31, 1925. He is survived by his wife and one son, Irving Ballard Crosby, and by a sister, Mrs. George E. Marsh, of Washington, D. C.

As a teacher, Professor Crosby counted among his students a host of now prominent engineers and geologists. His lectures were clear and logically presented. They were enriched by a wide acquaintance with geological phenomena in many different parts of the world. He possessed tact, a sense of humor, and infinite patience, backed by an eager desire to rouse thought. In the laboratory he was equally inspiring. As he was a careful and enthusiastic collector, the laboratories of geology, mineralogy, economic geology, and paleontology increased rapidly in efficiency. In its collections, as well as in so many other ways, the department owes very much to Professor Crosby. Excursions with him, either into the geologically rich local field or into more distant places, were always a source of inspiration and joy to his students as well as a source of new facts for their mental equipment.

To help and stimulate his students, Professor Crosby wrote many a syllabus and laboratory guide. Some of these, as "A Syllabus to Building Stones," "A Laboratory Guide to Elementary Lithology," and "Notes on Chemical Geology," were published by the Massachusetts Institute of Technology; others, as "Tables for the Determination of Common Minerals," were published outside.

While busy at the Institute and carrying on much research work, Professor Crosby was also connected with the Boston Society of Natural History. While an undergraduate student, his marked ability for original research was noted by Professor Alpheus Hyatt, who was then Professor of Paleontology at the Institute as well as Curator of the Museum of the Boston Society of Natural History. It followed that upon his graduation young Crosby was made assistant to Professor Hyatt at the Museum and was soon given charge of the geological and mineralogical collections there. These he proceeded to arrange according to their genesis and in a very attractive manner. They were soon widely used by

the teachers of natural science in the Boston schools, who visited them annually with hundreds of pupils. As one of these teachers has said:

"These collections Professor Crosby made into a demonstration of the evolutionary processes of inorganic nature. To the teacher they were an illuminating guide, to the child a story that goes right on."

These collections were regarded with pride and enthusiasm by Professor Hyatt.

In research Crosby was painstaking and thorough. His publications cover a wide field, including mineralogy, igneous rocks, glacial geology, physiography, metamorphism, economic geology, joints, faults, coral reefs, engineering geology, and underground waters.

His S. B. thesis at Massachusetts Institute of Technology, "Geology of Eastern Massachusetts," in 1876, gives the key to much of his subsequent work. It was to the unraveling of the complicated geology of this region that much of his energy was devoted. His three volumes on the "Geology of the Boston Basin" are but parts of a great work intended to occupy eight volumes. These three, published in 1893, 1894, and 1900, consider only the southern part of the basin—Cohasset, Hingham, and the Blue Hills. They stand alone as detailed reference books on this section. With much already accomplished on the central and northern parts of the basin, Professor Crosby was at work on these at the time of his death.

Of his published books and articles very many deal with Massachusetts. Others concern geological problems in Alaska, Arizonia, Colorado, Dakota, North Carolina, New York, and Rhode Island. A three months' camping trip to Trindad in 1878 and a trip to Cuba three years later gave rise to eight papers dealing with a variety of geological features in those islands; his European journeyings were also productive in this respect. His papers dealing especially with genesis include such widely diverse topics as the origin of eskers, the origin of pegmatites, five papers on the origin of joints, two on the classification of textures of rocks, and two on the origin of continents.

From his youth Crosby was greatly interested in ore deposits and a great impulse to his studies was received at the mines of the Clear Creek region in Colorado. His investigations of ore deposits, both for scientific and economic purposes, carried him far and wide—from Alaska to Arizona and from Vermont to California. From his travels he always brought back large suites of specimens for the collections of this department, and in this way were laid the foundations of the economic collections of the Institute.

Among the many districts which received his attention may be named the Treadwell mines in Alaska; the Michipicoten mines in Canada; the Washington deposits in Arizona and the Uhehebe in California; Park City, in Utah; Butte, in Montana. In fact, he covered in more or less detail the whole western mining region, besides many eastern deposits in Missouri, New York, and New Jersey. The collections made were carefully studied. Crosby described many rare minerals; wrote papers on non-metallic deposits and building stones; published a classification of economic geological deposits based on origin and structure; made a study of gold deposits of North Carolina and copper deposits of the contact metamorphic type from southern Arizona. With good reason Crosby may be considered as one of the most prominent of the economic geologists of the United States.

In the engineering profession Professor Crosby's advice as a consulting expert was highly valued. He was frequently called upon to solve questions relating to oil, ore, coal, kaolin, and clay deposits. In the courts his testimony was often asked as an aid toward the solution of legal controversies involving geological principles. It is, however, as an expert on water supply and its storage that he is best known in the engineering profession. His debut into this field may be said to begin with his appointment as consulting geologist to the Metropolitan Water Commission in Boston in 1895. He began studying the foundations for the Wachusett (Clinton) Dam, the North Dike and conditions along the route of the aqueduct tunnel. There were here some particularly puzzling problems as to the formations at the dam sites and the possibilities of deep leakage through preglacial gorges filled with sand and gravel. Later he did the geological work preparatory to the building of the dam across the tidal portion of the Charles River, the Boston subways and tunnels, the South Boston Dry Dock, the largest one in America, and for the new Technology buildings in Cambridge.

It was upon Crosby's expert geological knowledge that his classmate, the well-known civil engineer, John R. Freeman, depended. Quoting Mr. Freeman:

"It was on the result of about two months of most painstaking field-work by Crosby that the writer felt justified in recommending the flooding of the Big Meadows District in California, 40 square miles in area, over old lava beds, and with the assurance that it would hold water after a high dam was built. It was Crosby to whom the writer turned when seeking the best dam site on the Medina River in Texas, in a region abounding in giant springs, and trying to make sure before advising expenditure of perhaps a million dollars in a big dam, that the water would not disappear into some underground

cavern in the region of the great Balcones fault. It was Crosby whom the writer recommended as the most competent man that could be found anywhere for puzzling out questions of the tightness of the reservoir on the Conchos River in Mexico; Crosby to whom the writer turned for tracing the possible leaks in the limestone formation beneath the Hales Bar Dam on the Tennessee River; and again it was Crosby on whom we relied as to the excellence of the foundations afforded by the limestone ledge on which the great dam (the third largest in the world) across the Mississippi River at Keokuk now stands. It was Crosby on whom we relied for explanation of a most difficult dam site on the Missouri River at Holter, where the great dam now stands, and where two faults appeared to have joined forces immediately underneath the best location for a high dam. The Director of the U. S. Geological Survey told the writer a few years ago that Crosby had become probably the best adviser to be found in the United States upon geological conditions at a dam site presenting difficult foundations. His reports were models of clarity and skill in the use of the English language; and I recall that the late Professor Sedgwick, who himself was one of the best lecturers at the Massachusetts Institute of Technology, told me of once lingering just outside the door of Crosby's lecture room, fascinated by this literary quality. Together, Crosby and I studied mining prospects in Alaska, in Colorado, and on the borders of Death Valley, and thus I came to know Crosby's joy in his work, his kindness of heart, and the keen sense of humor that many did not suspect."

Professor Crosby was consulting geologist for the United States Reclamation Service in regard to several dam sites, among them that for the Arrow Dam, in Idaho, which is the highest in the world. He spent three months for the United States War Department studying the foundations for the Muscle Shoals Dam across the Tennessee River. He was consulting geologist to the Board of Water Supply of New York City (1906-1912), making investigations for the Ashokan and Kensico dams, the deep Hudson River siphon, the Catskill Aqueduct, and the underground water of Long Island. He was also consulting geologist for three dams in Spain, one of which, on the Pallaresa River, is the highest in Europe. This gives an idea, but by no means complete list, of Professor Crosby's work along these lines.

From his father, Crosby derived his own deep convictions about the sacredness of life and the wrong of needless killing. He shrank from inflicting pain on any living creature. As one of his close friends has said: "With Professor Crosby vegetarianism was not a fad, but a principle," as it similarly was with his father. Just as his father bore all the hardships of the Civil War, refusing all flesh food, trading his meat rations with other men for hardtack, so Otis never ate flesh food, no matter where his geological excursions took him or how meager the ration he found awaiting him.

Crosby's active humanitarianism extended in many directions. He was always a staunch advocate for the more liberal education of woman as he was for equal suffrage at the time this cause was extremely unpopular, just as his father stood for the freeing of the slaves when that cause was unpopular.

Crosby's sympathetic nature, his deep sense of humor, and his mental storehouse of poetry and anecdotes made him a wonderful companion. In spite of his handicap of deafness, a day with him in the field or an evening about the fireside was always a joyful and inspiring one.

Of societies, Professor Crosby was a fellow of the American Academy of Arts and Sciences, the Geological Society of America, the Seismological Society of America, American Institute of Mining Engineers, Economic Geologists, Boston Society of Natural History, Appalachian Mountain Club, and other bodies. He was twice awarded the Walker Prize of the Boston Society of Natural History. He also received the bronze medal for exhibits made at the Paris Exposition of 1900.

One likes to think of the many enduring monuments to his memory—the engineering structures that owe much of their stability to his research and advice, the books he wrote, many still standing as the only authority on the subjects of which they treat; the men who gained from him their first stimulus and encouragement in their geological life work, and—most enduring of all—the loving memories of his helpfulness, his courage, and good cheer in the hearts of those who knew him best.

Bibliography

1871. Cave at Hannibal, Missouri. Scientific American.
1872. Middle Park, Colorado. Scientific American.
Eight reports of the meetings of the Society of Arts. Scientific American.
1873. Affection and sagacity of a dog. American Naturalist, volume VII, pages 237-238.
1874. Life and work at Penikese. New York Tribune.
1875. Light of the sky. Proceedings of the American Academy of Arts and Sciences, volume IX, pages 425-428.
1876. Geology of eastern Massachusetts (graduating thesis). Abstract in President's Report, Massachusetts Institute of Technology, 1876.
1877. Notes on the surface geology of eastern Massachusetts. American Naturalist, volume XI, pages 577-587.
1878. Physical geography and geology of the Island of Trinidad. Proceedings of the Boston Society of Natural History, volume XX, pages 44-55.
1879. Native bitumen and the pitch lake of Trinidad. American Naturalist, volume XIII, pages 229-246.

Bitumen. Abstract of a lecture before the Boston Scientific Society. Science Observer, volume II, page 55.

Asphaltum and the pitch lake of Trinidad. Swiss Cross, volume I, page 172.

Occurrence of fossiliferous boulders in the drift of Truro, Cape Cod. Proceedings of the Boston Society of Natural History, volume XX, pages 135-140.

A possible origin of petrosilicious rocks. Proceedings of the Boston Society of Natural History, volume XX, pages 160-169.

How the appearance of a fault may be produced without fracture. Geological Magazine, new series, volume VI, pages 269-298.

Evidence of compression in the rocks of the Boston Basin. Proceedings of the Boston Society of Natural History, volume XX, pages 308-313.

1880. Biographical sketch of Levi S. Burbank. Proceedings of the Boston Society of Natural History, volume XXI, pages 49-51.

1880. Contributions to the geology of eastern Massachusetts. Occasional papers, Boston Society of Natural History, volume III, 288 pages.

On the age and succession of the crystalline formations of Guiana and Brazil. Proceedings of the Boston Society of Natural History, volume XX, pages 480-497.

Distorted pebbles in conglomerate. Proceedings of the Boston Society of Natural History, volume XX, pages 369-378.

Extension of the Carboniferous formation in Massachusetts. (With G. H. Barton.) American Journal of Science (3), volume XX, pages 416-420.

Geology of Frenchmans Bay, Maine. Proceedings of the Boston Society of Natural History, volume XXI, pages 49-51.

Pinite in eastern Massachusetts; its origin and geological relations. American Journal of Science (3), volume XIX, pages 116-122.

1881. On the classification of the textures and structures of rocks. Proceedings of the Boston Society of Natural History, volume XXI, pages 279-288.

Guides for science teaching. Boston Society of Natural History, volume XII.

Common minerals and rocks. Boston, 130 pages.

On the absence of joint structure at great depths and its relation to the forms of coarsely crystalline eruptive rocks. Geological Magazine, new series, volume VIII, pages 416-419.

1882. On the classification and origin of joint structure. Proceedings of the Boston Society of Natural History, volume XXII, pages 72-85.

The mountains of eastern Cuba. Appalachia, volume III, pages 129-142.

Elevated coral reefs of Cuba. Proceedings of the Boston Society of Natural History, volume XXII, pages 124-130.

1883. Probable occurrence of the Taconian System in Cuba. Science, volume II, page 740.

On the chasm called Purgatory in Sutton, Massachusetts. Proceedings of the Boston Society of Natural History, volume XXII, pages 434-436.

Origin of continents. Geological Magazine, new series, volume X, pages 241-252.

Origin and relations of continents and ocean basins. Proceedings of the Boston Society of Natural History, volume XX, pages 443-485.

1884. On the relations of the conglomerate and slate in the Boston Basin. Proceedings of the Boston Society of Natural History, volume XXIII, pages 7-27.

Chemical geology (note). Science, volume III, page 59.

The colors of natural waters. Science, volume III, pages 445-446.

1886. Guides to the Museum of the Boston Society of Natural History—Mineralogy. Boston, 184 pages.

Common minerals and rocks. Fourth edition, 75 pages, new. Boston.

Notes on joint structure. Proceedings of the Boston Society of Natural History, volume XXIII, pages 243-248.

On the great dikes at Paradise, near Newport, Rhode Island. (With G. H. Barton.) Proceedings of the Boston Society of Natural History, volume XXIII, pages 325-330.

1885. Colors of soils. Proceedings of the Boston Society of Natural History, volume XXIII, pages 219-222.

1887. Tables for the determination of common minerals. Boston, first, second and third editions.

The elevated pot-holes near Shelburne Falls, Massachusetts. Technology Quarterly, volume I, pages 36-38.

1888. Mineralogical notes. (With J. T. Greeley and C. L. Brown.) Technology Quarterly, volume I, pages 407-408.

Geology of the outer islands of Boston Harbor. Proceedings of the Boston Society of Natural History, volume XXIII, pages 450-457.

1888. On the joint structure of rocks. Technology Quarterly, volume I, pages 245-250.

Geology of the Black Hills, Dakota. Proceedings of the Boston Society of Natural History, volume XXIII, pages 488-517.

Method of instruction in mineralogy and structural geology in the Massachusetts Institute of Technology. Technology Quarterly, volume I, pages 187-194.

Quartzite and silicious concretions. Technology Quarterly, volume I, pages 397-407.

1889. Relations of the pinite of the Boston Basin to the felsite and conglomerate. Technology Quarterly, volume II, pages 248-252.

The Madison boulder. Appalachia, volume VI, pages 6-70.

1890. Composition of the till or boulder clay. Proceedings of the Boston Society of Natural History, volume XXX, pages 115-140.

The kaolin in Blandford, Massachusetts. Technology Quarterly, volume III, pages 228-237.

1891. On the contrast in color of the soils of high and low latitudes. Technology Quarterly, volume IV, pages 36-45.

1892. Geology of Hingham, Massachusetts. Proceedings of the Boston Society of Natural History, volume XXV, pages 490-512.

Biographical sketch of Thomas Sterry Hunt. Proceedings of the American Academy of Arts and Sciences, volume XIX, pages 367-372.

Guides to the Museum of the Boston Society of Natural History. Geological collections. Dynamical geology and petrography. Boston, 302 pages; also 86 plates, embracing 186 figures.

1893. Geology of the Boston Basin, volume I, part 1—Nantasket and Cohasset. Occasional papers, Boston Society of Natural History, volume IV, 177 pages.

The origin of parallel and intersecting joints. Technology Quarterly, volume VII, pages 27-48; American Geologist, volume XIII, pages 249-268.

1894. Geology of the Boston Basin, volume I, part 2—Hingham. Occasional papers, Boston Society of Natural History, volume IV, pages 178-288.

Distribution and probable age of the fossil shells in the drumlins of the Boston Basin. (With Hetty O. Ballard.) American Journal of Science (3), volume 48, pages 486-492.

A classification of economic geological deposits, based on origin and original structure. Technology Quarterly, volume VII, pages 27-48; American Geologist, volume 13, pages 249-268.

1895. Notes on the geology of the reservations. Report of the Metropolitan Park Commission, January, 1895, pages 55-68.

A classification of economic geological deposits. Engineering and Mining Journal, volume 59, pages 28-29.

1896. Glacial lakes of the Boston Basin. American Geologist, volume XVII, pages 128-130; Science, volume III, pages 212-213.

The sea mills of Cephalonia. (With F. W. Crosby.) Technology Quarterly, volume IX, pages 6-23.

Englacial drift. American Geologist, volume XVII, pages 203-234; Technology Quarterly, volume IX, pages 116-144.

1897. Geological and mineralogical work of Thomas Tracy Bouvé. Proceedings of the Boston Society of Natural History, volume XXVII, pages 236-239.

Biographical sketch of Thomas Tracy Bouvé. Proceedings of the American Academy of Arts and Sciences, volume 32, pages 340-344.

Notes on chemical geology—for Massachusetts Institute of Technology, 120 pages.

Contributions to the geology of Conanicut Island and Newport Neck. American Journal of Science (4), volume 3, pages 230-236.

Sandstone dikes accompanying the great fault of Ute Pass, Colorado, Bulletin 10, Geological Society of America, pages 141-164.

1898. Origin of pegmatite. (With M. L. Fuller.) Technology Quarterly, volume 9, pages 326-356; American Geologist, volume 19, pages 147-180 (1897).

1898. History of the Blue Hills Complex. Proceedings of the American Association for the Advancement of Science, volume XL, pages 130-135.

Archean-Cambrian contact near Manitou, Colorado. Bulletin of the Geological Society of America, volume 10, pages 141-164.

1899. Geology of the Wachusett Dam and Wachusett Aqueduct Tunnel of the Metropolitan Water Works in the vicinity of Clinton, Massachusetts. Technology Quarterly, volume 12, pages 68-96.

Geological history of the Nashua Valley during the Tertiary and Quaternary periods. Technology Quarterly, volume 12, pages 288-324.

1900. Geology of the Boston Basin, volume I, part 3, Blue Hills Complex. Occasional papers, Boston Society of Natural History, volume IV, pages 289-694.

Outline of the geology of Long Island in its relations to the public water supply. Technology Quarterly, volume XIII, pages 100-119.

Notes on the geology of the proposed dams in the valleys of the Housatonic and Ten-Mile rivers. Technology Quarterly, volume XIII, pages 120-127.

1901. Are the amygdaloidal melaphyres of the Boston Basin intrusive or contemporaneous? American Geologist, volume XXVII, pages 324-327.

Geological history of the hematite iron ores of the Antwerp and Fowler Belt in New York. Technology Quarterly, volume 14, pages 162-170; American Geologist, volume 29, pages 233-242.

The tripolite deposits of Fitzgerald Lake, near Saint John, New Brunswick. Technology Quarterly, volume 14, pages 124-127.

1900. On the origin of phenocrysts and the porphyritic texture in igneous rocks. American Geologist, volume 25, pages 299-310.

1902. Origin and relations of the auriferous veins of Algoma (western Ontario). Technology Quarterly, volume 15, pages 161-180.

A study of hard-packed sand and gravel. Technology Quarterly, volume 15, pages 260-264.

The origin of eskers. Proceedings of the Boston Society of Natural History, volume 30, 375-411.

1903. Memoir of Alpheus Hyatt. Bulletin of the Geological Society of America, volume 14, pages 504-512.

1903. A study of the geology of the Charles River estuary and Boston Harbor, with special reference to the building of the proposed dam across the tidal portion of the river. Technology Quarterly, volume 16, pages 64-92.

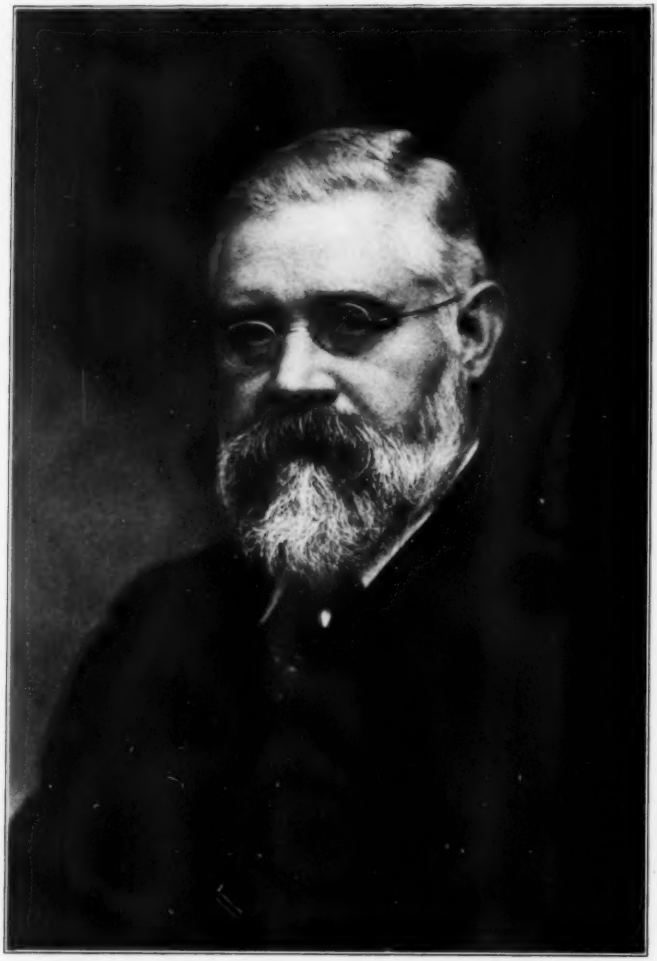
The hanging valleys of Georgetown, Colorado. Technology Quarterly, volume 16, pages 41-50; American Geologist, volume 32, pages 42-48.

1904. Structure and composition of the delta plains formed during the Clinton stage in the glacial lake of the Nashua Valley. Technology Quarterly, volume 16, pages 240-254; volume 17, pages 37-75.

Geology of the Western Aqueduct of the Metropolitan Water Works in Southboron, Framingham, Wayland, and Weston, Massachusetts. Technology Quarterly, volume 17, pages 101-116.

A descriptive catalogue of the building stones of Boston and vicinity. Technology Quarterly, volume 17, pages 165-185.

Notes on the water resources of Massachusetts. (With L. La Forge.) United States Geological Survey, Water Supply Paper 102, pages 94-117.



Notes on the water resources of Rhode Island. United States Geological Survey, Water Supply Paper 102, pages 119-129.

1905. Genetic and structural relations of the igneous rocks of lower Neponset Valley. American Geologist, volume 36, pages 34-48, 69-83.

The limestone granite contact of Washington Camp, Arizona. Technology Quarterly, volume 18, pages 171-190; American Institute of Mining Engineers, number 6, pages 1217-1238.

Underground waters of Massachusetts and Rhode Island. United States Geological Survey, Water Supply Paper 114, pages 68-79.

Water supply from the delta type of sand plane. United States Geological Survey, Water Supply Paper 145, pages 161-178.

1907. Ore deposits of the eastern gold belt of North Carolina. Technology Quarterly, volume 20, pages 280-286; American Institute of Mining Engineers, volume 19, pages 171-178.

Volcanic activity in Alaska. Science, new series, volume 26, pages 78.

1908. Outline of the geology of Long Island, New York. New York Academy of Science, volume 18, pages 425-429.

1912. Dynamic relations and terminology of stratigraphic conformity and unconformity. Journal of Geology, volume 20, pages 289-299.

1914. Buried gorge of the Hudson River and geologic relations of the Hudson Typhon of the Catskill Aqueduct. Abstract in Bulletin of the Geological Society of America, volume 25, pages 89-90.

Physiographic relations of serpentine, with special reference to the serpentine rock of Staten Island. Journal of Geology, volume 22, pages 582-593.

1925. Keystone faults. (With I. B. Crosby.) Bulletin of the Geological Society of America, volume 36, pages 623-640.

MEMORIAL OF SIR JOHN BURCHMORE HARRISON [1]

BY STANLEY SMITH

John Burchmore Harrison, late Director of Science and Agriculture and Government Geologist to British Guiana, belongs to the older school of versatile scientists whose interests and activities were not cramped by that specialization which of necessity characterizes science of our day. His researches extended into chemistry, botany, geology, and the coordination of these as agricultural science. To Harrison, British Guiana largely owes both her success in sugar production, which is her staple industry, and the development of her mineral resources.

He was a man of action as well as of ideas, a typical example of the men who leave the homeland to administer or to develop the outposts of its dominions, and who in the past have done so much to build up the younger English-speaking nations, both within and outside the British Confederacy.

[1] Manuscript received by the Secretary of the Society December 16, 1926.

The eldest son of John Harrison of Wilmslow, Cheshire, a Manchester cotton merchant, resident within the environs of Birmingham, he was born May 29, 1856. When old enough, he was sent to Edgbaston Proprietory School, a flourishing day school to which many of the professional and business men of Birmingham sent their sons. It was during the period at which Harrison was a pupil that the Rev. George Smith was appointed headmaster. Smith was a brilliant teacher of mathematics, and under him the school achieved notable success in this subject, in public examinations.

Chemistry was taught by George Gore, whose teaching was vitalized by his own researches, and thus the science was presented with a freshness and reality impossible from a teacher who merely retails predigested knowledge and the contents of text-books. Gore inspired as well as taught, and laid for the boy that foundation of thoroughness and method that characterized the work of the man. Under Gore, Harrison, who from the first seems to have possessed a natural aptitude for science, acquired a remarkable proficiency in chemistry, and so keen was his love for investigation that he fitted up a small laboratory at his own home.

In other subjects he showed good average ability, but no outstanding talent, nor did he distinguish himself at games. He has been described by those who knew him in his school days as a tallish, square-built, round-faced boy of a steady and quiet disposition.

Winning an open scholarship at Christ's College, he entered Cambridge in 1874, and there continued the study of chemistry under Liveing and Dewar, and to this added that of botany and agricultural science. The corporate life of a Cambridge college educates in an infinitely wider sense than in mere scholarship and technical knowledge. The close and friendly contact between don and undergraduate disseminates that appreciation of learning which the formal teaching in the lecture theater and laboratory can not give, and the social intercourse between young men of widely varied outlook and origin is an excellent preparation for all exigencies of public and professional life.

While always a serious student, Harrison's energy and high spirits found expression during his undergraduate days in directions other than those strictly approved by the university authorities. He took a prominent part in one at least of the conflicts between Gown and Town. Senior members of the university, recalling this memorable occasion, tell of how Harrison vanquished one of the law's most stalwart guardians. He graduated in 1878, taking a second class in the natural science trips.

After obtaining his degree he remained at Cambridge for a while, engaged in research in agricultural chemistry, and then spent a short

time pursuing similar work at the experimental station, Rothamsted, an institution which has done much to further agricultural science in England.

Upon the recommendation of Prof. G. D. Liveing and Prof. James Dewar, he was appointed in 1879 Island Professor of Chemistry and Agricultural Science at Barbados. He held this appointment until 1889, when he accepted the dual post of government analyst and professor of chemistry in British Guiana, and with this began his long connection with that colony.

In 1899 he was appointed Consulting Chemist to the Imperial Department of Agriculture for the West Indies, in 1902 Head of the Government Agricultural Investigations in British Guiana, in 1904 chairman of the Board of Agriculture, and in 1905 Director of the Consolidated Department of Science and Agriculture and also Government Geologist.

Harrison's most widely known and perhaps most appreciated work is that which affects the cultivations of the sugar cane and the production of sugar. Every sugar-growing country is directly or indirectly indebted to him.

His researches into the innumerable problems associated with sugar date back to his residence in Barbados, when, in conjunction with J. R. Bovell, he established, contrary to current opinion, the practicability of raising sugar from seed. Later he introduced seedling sugar canes into British Guiana, and in doing so reinstated an industry that was rapidly declining and was even threatened with extinction. At the special invitation of the government, he visited the United States in 1900 to advise on matters appertaining to sugar culture and on methods of sugar examination.

He did much to improve other tropical crops and to advance methods in the treatment of their products. In this connection rice, cotton, and balata may be mentioned.

It is his geological work that must necessarily appeal most directly to this Society, to which he was elected in 1902. Our science seems to have proved more attractive to him than any other, yet he does not appear to have turned serious attention to geological matters until confronted by the problems presented by the coral formations and oceanic deposits of the West Indies. As far as I can ascertain, his first geological paper, other than report of water supplies (written in collaboration with the late A. J. Jukes-Browne), dealt with West Indian Geology, was presented before the Geological Society of London in 1890, and was one of

a long series of cognate communications published in its Quarterly Journal.

In 1899 he received from that Society one of its awards, and in handing this to Mr. (after Sir) J. J. H. Teall for transmission, the President (Mr. William Whitaker) made the following remarks:

"I have the pleasure of handing over to you the balance of the Wollaston Fund for Prof. J. B. Harrison in acknowledgment of his work in the West Indies and British Guiana. In the course of the last eight years he has contributed several papers to the Society (in conjunction with Mr. A. J. Jukes-Browne and Mr. G. F. Franks), on the geology of Barbados, which have added much to our knowledge of old coral reefs, of the past physical geography of the region in which they occur, and of the oceanic deposits with which they are associated. In this work his ability as a chemist has been of great service. He has also done most of the field-work for the geological map of Barbados and has visited other West Indian islands and part of British Guiana in order to draw up official reports on soils and gold-bearing rocks. In the last of these visits, made last year, he suffered repeated and nearly fatal attacks of fever, from which he was slowly recovering in December, when we last heard from him."

During his forty-six years' residence in tropical America Harrison led many geological expeditions into the interior of British Guiana, to Grenada, and to several of the West Indian islands, and conducted important mineral surveys in British Guiana. The outcome of this geological work has been published in his numerous official reports. These reports cover a wide field of investigation, but are mainly concerned with geological reconnaissance, the occurrence of economic minerals, soil surveys and water supplies. To instance only some of his contributions to the economic geology of British Guiana, one may mention his discovery of important bauxite deposits, and of palladium and rhodium, his examination of the gold- and diamond-producing areas, and the detailed work and important conclusions concerning the relative soil fertility in the high and low-lying areas of the country. Reference may also be made to his extensive investigation into rock decay in tropical regions, problems upon which he was actively engaged at the time of his death.

He left his collection of over 2,000 microscope slides of British Guiana and West Indian rocks to Cambridge, requesting in his will that the collection might be placed in the Geological Museum "for the use and benefit of members of the said university or, at the discretion of the said university, of such students of geology who may desire to avail themselves of the same."

Harrison's published work, considerable as it is, inadequately represents his service to science. He administered three separate departments of public usefulness and supervised and conducted investigations in each of these. He was adviser in all scientific matters to British Guiana and was an authority of wide reputation on tropical agriculture.

His work and achievements have been acknowledged by a succession of well-deserved honors. On several occasions he received the thanks of the British Secretary of State for the Colonies; he was publicly thanked by the United States Government and was in 1918 appointed by the King member of the Executive Council of British Guiana. In 1901 he had conferred on him the Order of Saint Michael and Saint George (C. M. G.) and in 1921 knighthood.

Harrison was a man endowed with unusual powers of memory and had highly developed the faculty of clear-sighted vision. In matters of administration he was unrelenting in his efforts to give effect to a decision when once he had arrived at it. Efficient and untiring himself, he could not countenance incompetency or sloth in others, be they highly or lowly placed. Yet he was kindly and congenial, a very firm friend and one who was able to establish lasting ties of very real affection between himself and those with whom he worked.

He married, in 1881, Miss E. M. Hortense Carter, of Barbados, who bore him two children. The untimely death of his only son cast a deep shadow over the closing years of his life.

On February 8, 1926, Harrison died while still in harness. His death occurred on the eve of his retirement, to which he was looking forward, not as to a period of leisure, but as to a time of opportunity in which to further pursue his own researches untrammeled by public calls and the routine of official duties.

Valuable assistance in compiling this data has been rendered by Messrs. Harold Frere, W. Francis, H. M. Goodman, P. D. Innes, J. E. Marr, Col. Ernest Martineau, Sir Arthur Shipley, and others.

Bibliography*

(With A. J. Jukes-Browne.) Origin of the radiolarian earth of Barbados. Nature, volume 39, 1889, page 367.

(With A. J. Jukes-Browne.) Tertiary chalk in Barbados. Nature, volume 39, 1889, page 607.

(With A. J. Jukes-Browne.) Geology of Barbados, 1890, 64 pages and map.

* This bibliography notices geological publications only and does not include reports and papers dealing with purely agricultural and chemical matters, and, even as far as its scope extends, it may not be quite complete.

(With A. J. Jukes-Browne.) The geology of Barbados. Part I, The coral rocks of Barbados and other West Indian islands. Quarterly Journal of the Geological Society, volume XLVII (1891), pages 197-250.

(With A. J. Jukes-Browne.) The geology of Barbados. Part II, The oceanic deposits. Quarterly Journal of the Geological Society, volume XLVIII (1892), pages 170-226.

(With A. J. Jukes-Browne.) Notes on the chemical composition of some oceanic deposits. Quarterly Journal of the Geological Society, volume LI (1895), pages 313-328.

The rocks and soils of Grenada and Carriacou and the agricultural chemistry of Cacao, 60 pages. London, 1897.

(With H. L. Perkins.) British Guiana. Report on the geology of the Northwestern District, pages 1-16. Georgetown, Demerara, 1897.

British Guiana. Report on the rocks of the Aruka District. Northwestern District, pages 1-4. Part 2, Petrology, with notes on the microscopic structure of the rocks by J. J. H. Teall, pages 1-18. Georgetown, Demerara, 1898.

(With G. F. Franks.) The globigerina-marls (and basal reef rocks) of Barbados. Quarterly Journal of Geological Society, volume LIV (1898), pages 540-555.

(With A. J. Jukes-Browne.) The oceanic deposits of Trinidad (British West Indies). Quarterly Journal of the Geological Society, volume LV (1899), pages 177-188.

(With H. J. Perkins.) British Guiana. Report on the geology of the Essequibo, Potaro, Konowaruk, and Demerara rivers, pages 1-81. Georgetown, Demerara, 1900.

(With H. J. Perkins.) British Guiana. Report on the geology of the Mazaruni and Puruni rivers, pages 1-20. Georgetown, Demerara, 1900.

(On British Guiana.) Quarterly Journal of the Geological Society, volume LVII (1901), pages lxxxii-lxxxix.

British Guiana. Explanatory account of the details of the geological map of the Barima and Barama rivers, pages 1-7 and map. Georgetown, Demerara, 1901.

British Guiana. Explanation of the details of the geological map of parts of the Mazaruni and Puruni rivers, pages 1-10. Georgetown, Demerara, 1901.

British Guiana. Explanation of the details of the geological map of parts of the Essequibo, Potaro, and Demerara rivers, pages 1-11. Georgetown, Demerara, 1901.

(With A. J. Jukes-Browne.) The geology of Barbados. Geological Magazine, new series, decade IV, volume IX (1902), pages 550-554.

(With C. W. Anderson.) British Guiana. Preliminary report on the geology of the Lower Essequibo River, the Groete Creek District, and the Lower Cuyuni River, pages 1-12. Georgetown, Demerara, 1903.

(With C. W. Anderson.) British Guiana. Report on the geology of the Cuyuni River from Arawak Matope to the Akarabisi Creek, pages 1-19. Georgetown, Demerara, 1905.

(With C. W. Anderson.) British Guiana. Explanation of the geological map of parts of the Essequibo and Cuyuni rivers, pages 1-29. Georgetown, Demerara, 1906 (and map, 1905).

(With C. W. Anderson.) British Guiana. Report on the petrography of the Cuyuni and Mazaruni districts and of the rocks at Omai, Essequibo River, with some notes on the geology of part of the Berbice River, pages 1-71. Georgetown, Demerara, 1905.

(With E. Fowler and C. W. Anderson.) The geology of the goldfields of British Guiana, pages i-ix + 320, plates I-XXX and i-ix. London, 1905.

(With J. H. W. Park and others.) British Guiana. Artesian wells. Correspondence on the subject of artesian wells and further correspondence, pages 1-10 and 1-4. Georgetown, Demerara, 1909-1910.

The coral rocks of Barbados. Quarterly Journal of the Geological Society, volume LXIII (1907), pages 318-337.

(With K. D. Reid.) The residual earths of British Guiana commonly termed "laterite." Geological Magazine, new series, decade IV, volume VII (1910), pages 439-452, 488-595, 553-562.

British Guiana. Report on rock specimens from Akyma and Christianberg. Georgetown, Demerara, 1910.

On the formation of laterite from a practically quartz-free diabase. Geological Magazine, new series, decade V, volume VIII (1911), pages 120-123 and 353-356.

Formation of laterite. Geological Magazine, new series, decade V, volume VIII (1911), pages 477-478.

Report on soils from the Rupununi Savannah District of British Guiana, pages 1-17. Georgetown, Demerara, 1913.

Report on general composition of the water of certain rivers of British Guiana. Georgetown, Demerara, 1913.

British Guiana. Geology of the strata traversed by the D'Urban artesian well boring, 1913, 18 pages, Georgetown, Demerara.

British Guiana. Report on composition of samples collected during cattle trail survey. Georgetown, Demerara, 1916.

Reports and correspondence relative to bauxite in British Guiana, pages 1-31. Georgetown, Demerara.

The occurrence of reputed petroliferous areas in the Northwestern and Pomeroon districts of British Guiana, pages 1-27. Georgetown, Demerara, 1917.

Notes on the extraneous minerals in the coral limestones of Barbados. Quarterly Journal of the Geological Society, volume LXXV for 1919 (1920), pages 158-172.

(With C. W. Anderson.) The genesis of a fertile soil. West Indian Bulletin, volume XVIII, number 3, 1920, pages 77-98.

Note on the occurrence of rhyolitic pebbles in Antigua. West Indian Bulletin, volume XVIII, number 3, 1920, pages 99-101.

An occurrence of palladium and of rhodium in British Guiana. The Official Gazette, Georgetown, Demerara, 1924.

Digest of the results of the inquiries made concerning the occurrence of petroleum and pitch in British Guiana. Georgetown, Demerara, 1925.

(With C. L. C. Bourne.) Memorandum on the causes of an explosion in number 3 tunnel of the Peters Mine, Puruni River, on Saturday, April 1, 1916. Official Gazette, British Guiana, February 28, 1925, pages 1-2, 1925.

(With C. L. C. Bourne.) Memorandum on the occurrence of palladium amalgam—palladium mercuride—in British Guiana. Official Gazette, British Guiana, 1925, pages 1-3.

British Guiana and its resources. West Indian Committee Publication.

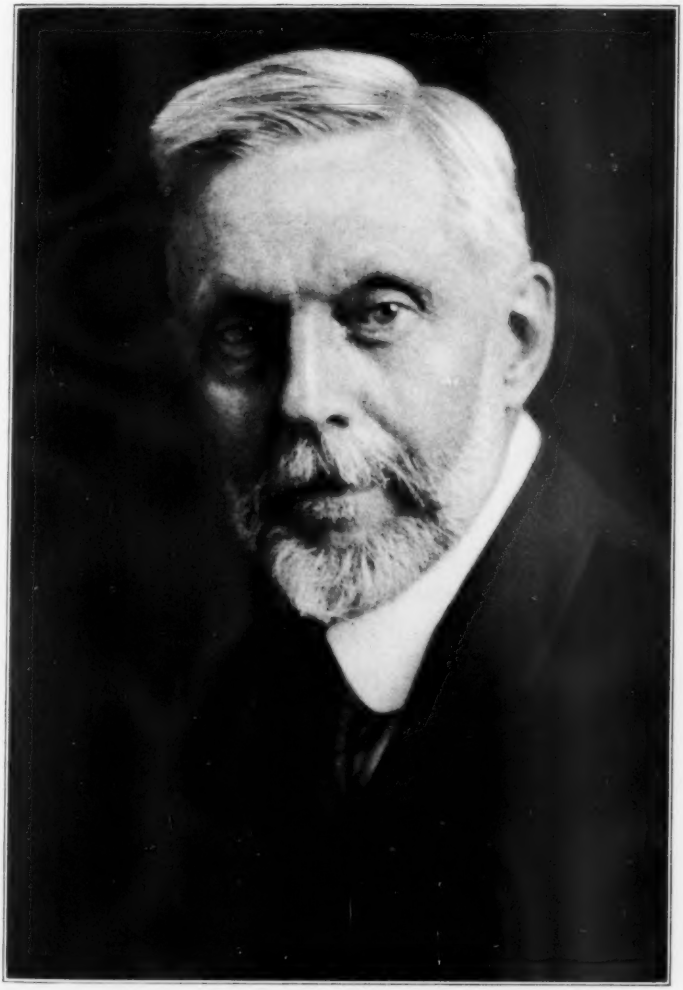
MEMORIAL OF FRANK HALL KNOWLTON [1]

BY DAVID WHITE

Frank Hall Knowlton, son of Julius Augustus and Mary Ellen Blackmer Knowlton, was born at Brandon, Vermont, September 2, 1860. He died at his home, Ballston, Virginia, November 22, 1926. Though reared on a farm, he very early developed a deep interest in natural history, which began with the collecting of birds' eggs at the age of 14. He soon learned to prepare and mount the skins of birds, and long before he entered the junior class of Middlebury College, in the fall of 1882, he had published his first scientific paper, "A List of the Birds of Brandon, Vermont," which appeared in the local weekly (*Brandon Union*) in 1878. With the study of birds he also took up the systematic botany of the flowering plants and higher cryptogams of the vicinity, making an herbarium and exchanging with other botanists. The nascent spirit of the naturalist was further cultivated to a glow that never thereafter faded, under the teaching of Ezra Brainerd and H. G. Seely at Middlebury College, from which he graduated in 1884 as Bachelor of Science, with honors in botany and geology. He paid his way through college by mounting birds and mammals for the college museum.

In our first official record of Knowlton we find him, shortly after graduating from college, working in the taxidermy shop of the Smithsonian Institution. Here his enthusiasm and ability were quickly recognized by the older naturalists of the Institution, and on November 2, 1884, he was, on recommendation of Prof. Lester F. Ward, appointed aid in botany and set at work in the small herbarium, then housed in the Department of Fossil and Living Plants. In 1887 he was made Assistant Curator of Botany, immediately in charge of the herbarium, which at that time occupied about 30 feet of running space along the wall of the south balcony in the old National Museum building, and consisted mainly of the specimens gathered by Professor Ward to illustrate the flora of the District of Columbia and vicinity. Later, this very

[1] Manuscript received by the Secretary of the Society January 31, 1927.



F. W. Knowlton

modest collection of dried plants was joined with others to form our great National Herbarium.

Meanwhile for several summers Knowlton was a member of Geological Survey parties in the Yellowstone National Park, where, in association with Hague, Peale, Iddings, Weed, and Ward, he not only gathered living plants for the herbarium, but took part in collecting the Tertiary fossil plants and woods, the elaboration of which was his first important contribution to systematic paleobotany. His first paleontological paper, "A new species of fossil wood (*Araucarioxylon arizonicum*) from Arizona and New Mexico," was published some time before his transfer, in June, 1889, to the Geological Survey, in which he was appointed Assistant Paleontologist. Except for a short time (1892-1893) when, on account of necessary drastic reduction of the Survey staff, he resumed his position in the United States National Museum, Knowlton continued work in the Geological Survey, where, in 1907, he gained the full rank of geologist, meanwhile having honorary positions in the Department of Geology and Paleontology in the National Museum.

For ten years (1887-1896) Knowlton was professor of botany in Columbian (now George Washington) University, where he received his doctor's degree in philosophy in 1896.

During his 42 years of scientific work under governmental auspices, Doctor Knowlton's publications embraced over 125 titles in paleobotany and nearly 100 in botany and ornithology, as is shown in the subjoined bibliography. He founded the *Plant World* and edited its first eight volumes, 1897-1904. In the preparation of the Century Dictionary, then a great undertaking in American lexicography, Knowlton assisted in writing the definitions in botany, beginning in H. He had sole charge of the botanical work of the Standard Dictionary, for which he wrote about 25,000 definitions. He assisted in preparing definitions for the 1900 edition of Webster's Dictionary and compiled botanical matter for the Jewish Encyclopedia.

Knowlton's descriptive papers treating of the Mesozoic and later floras run through 38 years and range geologically from the Trias of Arizona to the Pleistocene Carmichael clays of southwestern Pennsylvania, and geographically from the lignites of his native Brandon, Vermont, to the Kenai of the Aleutian chain.

His most important work in fossil plants relates to the successive floras of the Upper Cretaceous, and especially to the paleobotanical distinction between the Upper Cretaceous and the early Eocene floras—a task which involved the differentiation, locality by locality, of plant beds previously classed generally as Cretaceous, as well as some formerly re-

garded as Tertiary. Of his contributions to paleobotany, the papers of greatest value to geology, as viewed by the writer, are his "Fossil flora of the Vermejo and Raton formations of Colorado and New Mexico," published in 1918, his "Laramie flora of the Denver basin" (1922), his "Fossil flora of the Yellowstone National Park" (1899), and his "Fossil flora of the Montana formation" (1900). His elaboration of the Yellowstone flora, though lacking the broad knowledge of his later years, furnishes the sole basis for the determination of the geologic age of the great series of lavas and ash beds that fill the major portion of this broad structural basin, and of the similar flows of like composition in the surrounding region. To paleobotanists his catalogues of the Mesozoic and Tertiary plants of North America have been of outstanding value. They are used by students of the later floras in all lands and have rendered most important aid to the advance of paleobotany. A manuscript, "Flora of the Denver formation," though nearly complete, was not regarded by him as entirely ready for submission to the Chief Geologist of the Geological Survey for publication. Meanwhile Knowlton had resumed his studies of the fossil floras of the Tertiary lake basins and of the clays intercalated between the Tertiary lavas of eastern Washington. In the progress of industrial operations the removal of overlying basalt in the vicinity of Spokane had exposed intercalated clays carrying a profusion of fossil leaves in great perfection of impression. He had made a large collection of these leaves in the summer of 1926, and immediately after his return to Washington took up the systematic study of this collection.

Geologists may be interested to know, however, that zoologists rank Knowlton's "Birds of the World," a semi-popular general work of 873 pages, published in 1909, as his most important contribution to scientific literature. This comprehensive work in ornithology was written 30 years after his first scientific paper on "The Birds of Brandon, Vermont," noted above. He never ceased to be interested in ornithology, and for the greater part of his life in Washington was an active member of the American Ornithologists' Union.

Knowlton was genial, lovable, unfailingly loyal to his friends, and uncompromising in principle. In debate he was keen, analytical, and at times brilliantly sarcastic, but though his sarcasm occasionally approached acidity, forceful invective was invariably tempered with sunny humor, and friendliness and helpful kindness lay close beneath antagonism in defense of his scientific conclusions. He never was too busy to aid any applicant and was always especially interested in assisting the young aspirant in natural history. He was shy and unaggressive, even to reclusive-

ness—traits that made slow the recognition and pleasure of his delightful friendship.

Throughout his scientific career Knowlton was afflicted with chronic bronchial asthma, by which he was for considerable intervals more or less fully incapacitated. Undaunted, he took advantage of the isolation of confinement for work on some of his catalogues and made his weakness give opportunity for popularization of knowledge of birds and plants. He was reading proof of his last great undertaking, a popular work entitled "Plants of the Past" (now in press), when, during a brief illness, a comma placed casually marked the end of a career fruitful to science and cherished by his friends.

In 1887 Knowlton married Annie Stirling Moorehead, of Washington, D. C., who died January 26, 1890, leaving a daughter, Margaret. On October 3, 1893, he married Rena Genevieve Ruff, who, with their son, Frank Lester Knowlton, and Margaret (Mrs. Howard Lanahan), survive him.

Bibliography

1878. A partial list of the birds of Brandon, Vermont. The Brandon Union, December 13, 1878.

1880. Nesting of the duck hawk (*Falco communis*) in Vermont. Bulletin of the Nuttall Ornithological Club, volume V, number 1, page 57.

1881. Notes on the habits of the cliff swallow (*Petrochelidon tumifrons*). Bulletin of the Nuttall Ornithological Club, volume VI, number 1, page 55.

1882. A revised list of the birds of Brandon, Vermont, and vicinity. The Brandon Union, February 10, 1882.

Remarks on some western Vermont birds. Bulletin of the Nuttall Ornithological Club, volume VII, page 63.

1883. The winter wren (*Anothura troglodytes hiemalis*) in western Vermont. Bulletin of the Nuttall Ornithological Club, volume VIII, page 130.

The meadow lark (*Sturnella magna*) in Vermont in winter. Bulletin of the Nuttall Ornithological Club, volume VIII, page 182.

1884. The orchard oriole (*Icterus spurius*) in western Vermont. The Auk, volume I, page 390.

1885. List of the plants collected by Mr. Charles L. McKay at Nushaget, Alaska, in 1881, for the United States National Museum. Proceedings of the United States National Museum, volume VIII, 1885, pages 213-221.

1886. Arrangement of herbaria. Botanical Gazette, volume XI, page 121.

A collection of exotics. Botanical Gazette, volume XI, page 250.

Alaskan plants. Botanical Gazette, volume XI, page 340.

A résumé of the algo-lichen hypothesis. The American Monthly Miscellaneous Journal, volume VII, Washington, pages 101-105.

Additions to the flora of Washington and vicinity from April 1, 1884, to April 1, 1886. Proceedings of the Biological Society of Washington, volume III, 1884-86, pages 106-132.

1887. *Solidago bicolor* L. and var. *concolor* Torrey and Gray. Botanical Gazette, volume XII, page 111.

Solidago erecta Pursh. Botanical Gazette, volume XII, 1887, page 114.

1888. A protest against bird murdering. The American Angler, volume XIII, February 25, page 118.

A defense of small birds. The Utica (New York) Herald, February 27.

The English sparrow question. The Brandon Union (Vermont), March 16.

A visit to a fossil forest. The Brandon (Vermont) Union, January 20.

Great fossil forests: one of the wonders of the Yellowstone National Park. The Evening Star, Washington, D. C., February 6, 1888.

Lichens from the Easter Islands. The Botanical Gazette, volume XIII, page 94, 95.

Description of a new species of the genus *Chara*. The Botanical Gazette, volume XIII, pages 156, 157, 2 figures.

Malformation of a cabbage leaf. Garden and Forest, volume I, number 25, August 15, 1888, page 296, figure 48.

Potomac fossils. The Washington (D. C.) Post, November, 1888. The Evening Star (Washington, D. C.), November, 1888. The Omaha Bee, November, 1888.

New species of fossil wood (*Araucarioxylon arizonicum*) from Arizona and New Mexico. Proceedings of the United States National Museum, volume XI, pages 1-4, plate I.

Description of two new species of fossil coniferous wood from Iowa and Montana. Proceedings of the United States National Museum, volume XI, pages 5-8, plates II, III.

Description of two species of *Palmoxylon*, one new, from Louisiana. Proceedings of the United States National Museum, volume XI, 1888, pages 89-91, plate XXX.

Trinity fossils from Arkansas. In R. T. Hill, Annual Report, Geological Survey of Arkansas, 1888, volume II, page 152.

1889. The fossil wood and lignites of the Potomac formation. The American Geologist, volume III, February, 1889, pages 99-106.

The fossil wood and lignites of the Potomac formation (abstract). Cleveland Leader, August 7, 1889. Proceedings of the American Association for the Advancement of Science, volume XXXVII, pages 206-208.

Description of a problematic organism from the Devonian of the falls of the Ohio. American Journal of Science, volume XXXVII, March, pages 202-209, 3 text figures.

Description of fossil woods and lignites from Arkansas. Annual Report, Geological Survey of Arkansas for 1889, volume II, pages 249-267, plates IX-XI.

Fossil wood and lignite of the Potomac formation. Bulletin of the United States Geological Survey, number 56, pages 1-72, plates I-VII.

1890. Notes on Triassic plants from New Mexico. By William M. Fontaine and F. H. Knowlton. Proceedings of the United States National Museum, volume XIII, pages 281-285, plates XXII-XXVI.

An account of the progress in botany for the years 1887-1888. Smithsonian Report for 1888, pages 475-496.

A revision of the genus *Araucarioxylon* of Kraus, with compiled descriptions and partial synonymy of the species. Proceedings of the United States National Museum, volume XII, pages 601-617.

1891. Directions for collecting recent and fossil plants. Part B of Bulletin of the United States National Museum, number 39, pages 1-46, figures 1-10.

The Century Dictionary—Cryptogamic botany, H–Z. The Century Co., New York.

Report on fossil plants from Pinnacle Pass, near Mount Saint Elias, Alaska. Contributed to I. C. Russell's paper: An expedition to Mount Saint Elias, Alaska. National Geographic Magazine, volume III, May 29, 1891. Appendix II, pages 199-200.

1892. Fossil flora of the Bozeman coal field. Proceedings of the Biological Society of Washington, volume VII, 1892, pages 153-154.

Flora of the Dakota group. By Leo Lesquereux. Edited by F. H. Knowlton. Monograph XVII, United States Geological Survey, pages 1-400, plates I-LXVI, 1892.

Letter to I. C. Russell on fossil wood from Triassic of North Carolina and review of the Triassic plants of Prince Edward Island. United States Geological Survey, Bulletin 85, correlation papers: The Newark system, by I. C. Russell, 1892, page 29.

Report on interglacial earth from Iowa. In W J McGee—paper on the Pleistocene history of northeastern Iowa. United States Geological Survey, Eleventh Annual Report, part I, 1891, page 493.

1893. Bread-fruit trees in North America. Science, volume XXI, January 13, 1893, page 24.

The flora of the Dakota group: A reply. The Botanical Gazette, volume XVIII, January, 1893, pages 37-39.

Description of a new fossil species of *Chara*. The Botanical Gazette, volume XVIII, pages 141, 142, figures 1-3.

A simple point in nomenclature. Bulletin of the Torrey Botanical Club, volume XX, May, 1893, pages 212-213.

Note on a supposed new endogenous tree from the Carboniferous. Science, volume XXI, June 16, 1893, pages 332-333.

Notes on a few fossil plants from the Fort Union group of Montana, with a description of one new species. Proceedings of the United States National Museum, volume XVI, 1893, pages 33-36, plates I-II.

Annotated list of the fossil plants of the Bozeman, Montana, coal field, with table of distribution and description of new species. Bulletin

of the United States Geological Survey, number 105, pages 43-67, plates V and VI.

Standard Dictionary of the English Language, volume I, A–L. Botany, by F. H. Knowlton. Issued December 25, 1893.

1894. Letter relating to fossil wood from Black Hills, Dakota. See Lester F. Ward's paper, Cretaceous rim of the Black Hills. Journal of Geology, volume II, number 3, April-May, 1894, pages 260-261.

A review of the fossil flora of Alaska, with descriptions of new species. Proceedings of the United States National Museum, volume XVII, 1894, pages 207-240, plate IX.

Fossil flora of Alaska (abstract). Bulletin of the Geological Society of America, volume 5, 1893 (June, 1894), pages 573-590.

Fossil plants as an aid to geology. The Journal of Geology, volume II, number 4, May-June, 1894, pages 365-382.

Story of the rocks—the fossil plants found in the Potomac formation. The Evening Star (Washington, D. C.), August 11, 1894, page 14, figures 1-11.

Letter relating to height of trees in Illinois. The Vidiologist (Alameda, California), volume II, number 1, September, 1894, page 14.

Birds of south-central Montana. By Charles W. Richmond and F. H. Knowlton. The Auk, volume XI, October, 1894, pages 298-308.

A new fossil hepatic from the Lower Yellowstone in Montana. Bulletin of the Torrey Botanical Club, volume 21, number 10, October, 1894, pages 458-459, plate 219.

Sulphur showers, an erroneous name given to pine pollen carried by the wind. The Evening Star (Washington, D. C.), December 1, 1894, page 3.

Red snow. A curious plant which thrives amid Arctic rigors. The Evening Star (Washington, D. C.), December 1, 1894, page 6.

Standard Dictionary of the English Language, volume II, New York, 1894. M–Z, Botany, under direction of F. H. Knowlton.

1895. Vanilla and its cultivation. Popular Science News, volume XXIX, number 1, January, 1895, pages 1–2, figures in text.

Something about lichens. Popular Science News, volume XXIX, number 3, March, 1895, pages 35, 36, figures (in text) 1-7.

Bread-fruit trees in the United States. Popular Science News, volume XXIX, number 3, March, 1895, page 4.

Something about lichens. Article condensed from that in Popular Science News, March, 1895. Public Opinion, volume XVIII, March 14, 1895, pages 252.

The oldest dicotyledons. Popular Science News, volume XXIX, number 4, April, 1895, pages 49-51, figures 1-9; number 5, May, 1895, pages 66-68, figures 10-20.

Use of the initial capital in specific names of plants. Science, second series, number 16, April 19, 1895, volume I, pages 423, 424.

The uncanny bat. Some facts of interest about this curious animal. The Evening Star (Washington, D. C.), April 20, 1895, page 17.

Intelligent swallows. The Youth's Companion, number 3544, April 15, 1895, page 210.

Fossil forests of the Yellowstone National Park. The Epoch, volume I, number 1, April, 1895, pages 18, 19.

Reasons for the scientific names of plants and animals. Popular Science News, volume XXIX, July, 1895, page 102.

Letter relating to the age of the auriferous gravels in H. W. Turner's paper, Auriferus gravels of the Sierra Nevada. American Geologist, volume XV, number 6, June, 1895, page 374.

Report on small collection of fossil plants from Poverty Hill and Monte Cristo Mine on Spanish Peak, California. Submitted by H. W. Turner, January 31, 1895. American Geologist, volume XV, number 6, June, 1895, page 377.

Report on small collection of fossil leaves from Volcano Hill, Placer County, California. Submitted for examination by H. W. Turner. American Geologist, volume XV, number 6, June, 1895, pages 377-378.

Notes on the examination of a collection of interglacial wood from Muir Glacier, Alaska. Journal of Geology, volume III, number 5, July-August, 1895, pages 527-532.

Some facts about peanuts. Popular Science News, volume XXIX, number 8, August, 1895, pages 122-123.

Charles Christopher Parry (an account of his life and work). Bulletin of the Philosophical Society of Washington, volume 12, pages 497-499.

Sulphur showers. Popular Science News, volume XXIX, number 9, September, 1895, page 130, 2 cuts.

Report upon a small collection of fossil plants from Black Hills, near Belvidere, Kansas, collected by Prof. R. T. Hill in August, 1894. In Hill's article, Outlying areas of the Comanche series in Kansas, Oklahoma, and New Mexico. American Journal of Science, volume L, September, 1895, pages 212-214.

Description of a new problematical plant from the Lower Cretaceous of Arkansas. Bulletin of the Torrey Botanical Club, volume 22, number 9, September, 1895, pages 387-390, figures (in text) 1-3.

Report on a small collection of fossil plants from Old Port Caddo Landing, on Little Cypress Bayou, Harrison County, Texas, made by T. Wayland Vaughan. The American Geologist, volume XVI, November, 1895, pages 308-309.

Alfalfa or lucerne. Popular Science News, volume 29, December, 1895, page 180.

A new species of turkey. The Feather, volume I, number 3, December, 1895, page 75 (note).

A million dollar feather cloak. The Feather, volume I, number 3, December, 1895, page 82 (note).

Number of kinds of woodpeckers. The Feather, volume I, number 3, December, 1895, page 83 (note).

Number of parrots in the world. The Feather, volume I, number 3, December, 1895, page 83 (note).

1896. Yellowstone's death gulch. Popular Science News, volume XXX, number 1, January, 1896, pages 1, 2.

Bacteria in milk (abstract). Popular Science News, volume XXX, number 1, January, 1896, page 16.

Bacteria in milk (abstract). Popular Science, volume XXX, number 1, January, 1896, page 16.

The great auk. The Feather, volume I, number 4, January, 1896, pages 111-112, 3 figures in text.

Birds laying up food. The Feather, volume I, number 4, January, 1896, page 112.

The migration of birds to the moon. The Feather, volume I, number 4, January, 1896, page 113.

A fish-hawk's nest. The Feather, volume I, number 4, January, 1896, page 113.

Cacao, coca, and cocoanut. Merck's Market Report, New York, fifth year, number 3, February 1, 1896, pages 57-59, figures in text.

The largest known flower. The Youth's Companion, volume 17, number 6, February 6, 1896, page ii, figure in text.

The dodo. The Feather, volume I, number 5, February, 1896, pages 156-157, figure in text.

The winter home of the bobolink. The Feather, volume I, number 5, February, 1896, page 160, figure in text.

The ruby-throated humming bird. The Feather, volume I, number 5, February, 1896, page 160.

Hawks and owls. Popular Science News, volume XXX, number 3, March, 1896, page 57, 2 figures in text.

Some inconsistencies in plant nomenclature. The Botanical Gazette, volume XXI, February, 1896, pages 82-85.

A Carboniferous tree. Popular Science News, volume XXX, number 4, April, 1896, page 87, figure in text.

A rare bird. The Feather, volume I, March, 1896, page 204.

Fossil birds (short note). The Feather, volume I, March, 1896, volume I, page 207.

Cultivated plants which are rare in a wild state (note). Popular Science News, volume XXX, number 2, February, 1896, page 26.

Pikes Peak fossils (note). Popular Science News, volume XXX, number 4, April, 1896, page 87.

Saffron and safflower. Merck's Market Report, New York, fifth year, April 1, 1896, pages 165-167, portrait and figures in text.

American amber-producing tree. Science, new series, volume III, number 68, April 17, 1896, pages 582-584, figures in text.

The papaw, and its use as a food for invalids. Merck's Market Report, fifth year, number 9, May 1, 1896, page 217, figure in text.

Death Valley. One in the Yellowstone Park that ranks with Java. The Avant Courier, Bozeman, Montana, May 23, 1895. (Copied from Popular Science News.)

A natural bear-trap. Recreation, volume IV, number 6, June, 1896, page 297.

Description of a supposed new species of fossil wood from Montana. Bulletin of Torrey Botanical Club, volume 23, number 6, June, 1896, pages 250, 251, plate 271.

What is a yam, where and how large does it grow, etcetera? Popular Science News, volume XXX, number 7, July, 1896, page 162.

Anise and star anise. Merck's Market Report, July 15, 1896, pages 352, 353, 4 figures in text.

American amber-producing tree. [Reprinted from Science.] Johns Hopkins University Circular, volume XV, number 126, June, 1896, page 94.

The Tertiary floras of the Yellowstone National Park. American Journal of Science, fourth series, volume II, July, 1896, pages 51-58.

The Carolina paroquit—the only North American representative of the parrot family. The Feather, volume II, number 1, October, 1896, pages 33-34, figure in text.

Wonders of the sundew. Popular Science News, volume XXX, November, 1896, pages 246-248, figures 1-5.

Description of two supposed new species of fossil trees from the Purbeck beds of the Isle of Portland and the Wealden of the Isle of Wight, England. In L. F. Ward's paper, "Some analogies in the Lower Cretaceous of Europe and America." United States Geological Survey, Sixteenth Annual Report, November, 1896, pages 495-496, plate CII, figures 2-5.

The genus *Nestor*. The Osprey, volume 1, number 3, November, 1896, pages 31-33, 2 figures in text.

The jungle fowl (note). The Feather, volume II, number 2, November, 1896, pages 77, 78.

The Ranunculaceæ. Merck's Market Report, fifth year, number 22, November, 15, 1896, pages 594, 595, figures 1-6 in text.

A trunkless tree. Popular Science News, volume XXX, December, 1896, page 281, 3 figures in text.

Report on a collection of fossil plants from Morgantown, West Virginia. In I. C. White's paper, "Origin of the higher terrace deposits of the Monongahela River." American Geologist, volume XVIII, December, 1896, pages 370-372.

Night hawk catching insects by electric light. The Osprey, volume I, number 4, December, 1896, page 53.

How plants are grouped. Merck's Market Report, volume V, number 24, December, 15, 1896, pages 655, 656.

1897. Report on the fossil plants collected in Alaska in 1895, as well as an enumeration of those previously known from the same region, with a table showing their relative distribution. United States Geological Survey, Seventeenth Annual Report, 1895-1896. Appendix I to Dall's report on "Coal and lignite of Alaska," (1896 [1897]), pages 876-897.

Stratigraphy and paleontology of the Laramie and related formations in Wyoming, by T. W. Stanton and F. H. Knowlton. Abstract in

Journal of Geology, volume IV, number 1, January-February (1897), pages 102, 103.

Stratigraphy and paleontology of the Laramie and related formations in Montana, by T. W. Stanton and F. H. Knowlton. Bulletin of the Geological Society of America, volume 8, pages 127-156. Dated February 17, but not issued until March 18, 1897.

Garden craft. A review of L. H. Bailey's The Horticulturist's Rule Book: Nursery Book and Plant Breeding. Public Opinion, volume XXII, March 18, 1897, pages 344, 345.

Cubebs. Merck's Market Report, March 15, 1897, pages 172, 173.

A cannibalistic woodpecker. Popular Science News, volume XXXI, number 4, April, 1897, page 74.

Major Charles E. Bendire. The Osprey, volume I, number 7, March, 1897, pages 87-90, portrait.

Pityoxylon Hollicki Knowlton, n. sp. [Description of a new species of fossil wood from Cliffwood, New Jersey.] A. Hollick, Transactions of New York Academy of Sciences, volume XVI, 1897, pages 134-136, figures (1 in text, 1, 2).

Two deer in half a minute. Recreation, volume VI, number 5, May, 1897, page 357.

The opium poppy. Popular Science News, volume XXXI, number 9, September, 1897, page 199.

Sensitiveness of the sundrew. The Plant World, volume I, number 1, October, 1897, pages 7, 8.

Notes on Artocarpus. The Plant World, volume I, number 1, October, 1897, page 12.

Editorial. The Plant World, volume I, number 1, October, 1897, pages 13, 14.

A remarkable lily. The Plant World, volume I, number 1, October, 1897, page 16.

Some early American botanists—Amos Eaton. Plant World, volume I, number 2, November, 1897, pages 17, 18, portrait.

Editorial. (The amateur in botany.) Plant World, volume I, number 2, November, 1897, pages 29, 30.

Gelsemium and its habitat. Merck's Report, volume VI, number 23, December 1, 1897, page 723, figure in text.

National forests and their preservation. The Plant World, volume I, December, 1897, pages 40, 41.

Editorial. (Reason for scientific names.) Plant World, volume I, December, 1897, pages 45, 46.

1898. The standing fossil forests of the Yellowstone National Park. Plant World, volume I, number 4, January, 1898, pages 53-55.

Note on catalogue of the Cretaceous and Tertiary plants of North America. Plant World, volume I, number 4, January, 1898, page 60.

Editorial. (New classification of plants.) Plant World, volume I, number 4, January, 1898, page 60.

Editorial. (Nomenclature.) Plant World, volume I, number 5, February, 1898, pages 77, 78.

Abstract of article by Dr. Bessey on the functions of *Stomata*. Plant World, volume I, number 5, February, 1898, pages 79, 80.

Editorial notes. Plant World, volume I, number 6, March, 1898, page 93.

Editorial notes. Plant World, volume I, number 7, April, 1898, page 109.

Notes on a botanical trip to southern Florida. Plant World, volume I, number 7, April 1898, page 111.

The elephant tree. Plant World, volume I, number 8, May, 1898, pages 113-116, plate V.

Editorial notes. Plant World, volume I, number 8, May, 1898, pages 125, 126.

Editorial notes. Plant World, volume I, number 9, June, 1898, pages 141, 142.

Note on taking up of copper by pine trees. Plant World, volume I, number 9, June, 1898, page 142.

Editorial notes. Plant World, volume I, number 10, 1898, pages 157, 158.

Note on sulphur showers. Plant World, volume I, number 10, July, 1898, page 160.

Editorial notes. Plant World, volume I, number 10, August, 1898, pages 173, 174.

The torch tree. Plant World, volume II, number 1, October, 1898, pages 12-14, plate II.

In a coal swamp. Plant World, volume II, number 2, November, 1898, pages 21-23, plate III.

Editorial notes. Plant World, volume II, number 2, November, 1898, page 33.

Editorial notes. Plant World, volume II, number 3, December, 1898, pages 49, 50.

Observations on the chimney swift. The Osprey, volume III, number 2, October, 1898, pages 27, 28.

Report on the fossil plants of the Payette formation. United States Geological Survey, Eighteenth Annual Report, for 1896-1897, part III, pages 721, 744, plates XCIX-CII.

A catalogue of the Cretaceous and Tertiary plants of North America. United States Geological Survey, Bulletin, number 152, 1898, pages 1-247.

1899. Editorial. Plant World, volume II, number 5, February, 1899, page 85.

How fossil wood is studied. Plant World, volume II, number 6, March, 1899, pages 95-98, plate VI.

Fossil plants associated with the Calaveras skull. Plant World, volume II, number 8, May, 1899, page 115.

Alvin Wentworth Chapman. Plant World, volume II, number 9, June, 1899, pages 141-143, 2 portraits.

Editorials. Plant World, volume II, number 9, June, 1899, page 183.

Report on some fossil wood from the Richmond basin, Virginia. United States Geological Survey, Nineteenth Annual Report, part II, 1899, pages 516-519, plate LII.

Fossil flora of the Yellowstone National Park. United States Geological Survey, Monograph 32, part II, 1899, pages 651-882, plates LXXVII-CXXI.

1900. Editorial. Plant World, volume III, number 2, February, 1900, page 29.

Selaginella apics found fossil. Plant World, volume III, number 2, February, 1900, page 31.

Culture of Tiarella. Plant World, volume III, number 2, February, 1900, page 31.

Editorials. Plant World, volume IV, number 4, April, 1900, page 61.

Editorial. Plant World, volume III, number 7, July, 1900, page 109.

Editorial. Plant World, volume III, number 9, September, 1900, page 141.

Notes for the beginner in the study of mosses. Plant World, volume III, number 10, October, 1900, pages 145-148, plate V.

Editorial. Plant World, volume III, number 11, November, 1900, page 174.

Irises. Plant World, volume III, number 12, 1900, pages 179-181, figures in text.

Flora of the Montana formation. United States Geological Survey, Bulletin 163, 1900, pages 1-118, plates I-XIX.

Fossil plants associated with the lavas of the Cascade Range. United States Geological Survey, Twentieth Annual Report, part III, 1900, pages 37-64, plates I-III.

1901. Variation in leaves of *Lonicera japonica*. Plant World, volume IV, number 1, January, 1901, page 8.

Editorial. Plant World, volume IV, number 1, January, 1901, page 16.

Hura crepitans. Plant World, volume IV, number 2, February, 1901, page 35.

Fossil hickory nuts. Plant World, volume IV, number 3, March, 1901, pages 51, 52.

Fossil sequoias in North America. Plant World, volume IV, number 6, June, 1901, page 111.

Editorial. Plant World, volume IV, number 3, March, 1901, page 58.

A fossil flower. Plant World, volume IV, number 4, April, 1901, pages 73, 74.

Editorial. Plant World, volume IV, number 4, April, 1901, page 78.

Common plants in the John Day Basin, Oregon. Plant World, volume IV, number 9, September, 1901, page 176.

Editorial. Plant World, volume IV, number 9, September, 1901, page 179.

A fossil nut pine from Idaho. Torreya, volume I, number 10, October, 1901, pages 113, 114, 2 figures in text.

1902. Change of name of *Ficus? hesperia* from vicinity of Ashland, Oregon. Proceedings of the Biological Society of Washington, volume XV, April 25, 1902, page 86.

Fossil flora of the John Day Basin, Oregon. United States Geological Survey, Bulletin 204, pages 1-153, plates I-XVII.

Suggestions for the preservation of our native plants. Journal of the New York Botanical Garden, volume III, number 27, 1902, pages 41-47.

Notes on the fossil fruits and lignites of Brandon, Vermont. Bulletin of the Torrey Botanical Club, volume 29, November, 1902, pages 635-641, plate 25.

Description of a new fossil species of *Chara*. Torreya, volume 2, number 5, May, 1902, pages 71, 72, figure in text.

Preliminary report on fossil plants from the State of Washington, collected by Henry Landes, 1901. Annual Report, Washington Geological Survey, volume I, for 1901, pages 32, 33. [1902.]

The journeyings of birds. Popular Science Monthly, volume LX, February, 1902, pages 323-335.

1903. The home garden and greenhouse. Notes: What to plant; The paper-white narcissus; Temperature of water for plants; A good greenhouse plant; Calla lily disease; The water hyacinth. Plant World, volume VI, number 1, January, 1903, pages 19-22.

The home garden and greenhouse. Notes: Chrysanthemums; Calla lilies; Poinsetta; Paper-white narcissus; A curious begonia; Geraniums from seed; Pansies in the Washington parks. Plant World, volume VI, February, 1902, pages 44-46.

A harbinger of spring. Plant World, volume VI, March, 1903, pages 60, 61, plates 11, 12.

The home garden and greenhouse. Notes: A curious begonia; Starting seed; Propagating shrubs; The cold frame; The cutting box. Plant World, volume VI, March, 1903, pages 67-69.

The publication of rejected names. Science, new series, volume XVII, number 430, March 27, 1903, pages 506-508.

Editorial. Plant World, volume VI, April, 1903, pages 91, 92.

The home garden and greenhouse. Notes: Too much water; Magnolia stellata; Insect pests; Nasturtiums for the greenhouse; Streptosolen for the greenhouse; Management of the greenhouse. Plant World, volume VI, April, 1903, pages 93-95.

Editorials. Plant World, volume VI, May, 1903, page 118.

The home garden and greenhouse. Notes: Plants from the Philippines; Chrysanthemums; *Amorph. phallus simlense;* Farm crops; Pollination of apple blossoms; Date palms; The tree peony; Easter lily bulbs; Dutchman's pipe for a porch vine; Oranges in California. Plant World, volume VI, May, 1903, pages 119-121.

Editorial. Plant World, volume VI, June, 1903, page 142.

The home garden and greenhouse. Notes: The Japanese snowball; Pink-flowered locust; Easter lilies; Raising cucumbers; Strawberries; Hellebore for currant worms; Bedding begonias; Failure of narcissus to bloom. Plant World, volume VI, number 6, June, 1903, pages 143, 144.

The home garden and greenhouse. Notes: Protection against cutworms; Tuberous-rooted begonias; The Easter lily from seed; Works on landscape gardening. Plant World, volume VI, number 7, July, 1903, pages 169, 170.

Editorial. Plant World, volume VI, number 11, November, 1903, page 269.

The home garden and greenhouse. Notes: Primulas; Freesias; Cyclamen; The Poinsettia; *Lilium harrisi*, etcetera. Plant World, volume VI, number 11, December, 1903, page 281.

1904. The misuse of "formation" by ecologists. Science, new series, volume XIX, number 481, March 18, 1904, pages 467, 468.

Fossil plants from Kukak Bay, Harriman Alaska Expedition, volume IV, 1904, pages 149-162, plates XXII-XXXIII.

Home garden and greenhouse. Notes: The Chinese flowering apple; Propagation of carnations. Plant World, volume VII, January, 1904, pages 23, 24.

Home garden and greenhouse. Notes: Propagation of carnations; Getting ready for spring; Winter bulbs. Plant World, volume VII, February, 1904, pages 45-47.

Home garden and greenhouse. Notes: Orchids; Calla lilies. Plant World, volume VII, March, 1904, pages 73-75.

Home garden and greenhouse. Notes: Japanese maples; Spring flowering shrubs. Plant World, volume VII, April, 1904, pages 100, 101.

1905. Fossil plants of the Judith River beds. In Stanton and Hatcher, United States Geological Survey, Bulletin 257, 1905, pages 129-168, plates XIV-XIX.

1906. Report on fossil plants from one mile east of Cumberland, Wyoming. In Veatch, American Journal of Science, fourth series, volume 21, 1906, page 459.

Lists of Fort Union plants. In A. G. Leonard, United States Geological Survey, Bulletin 316, 1906 [1907], pages 201, 202.

1907. Description of a collection of Kootenai plants from the Great Falls coal field of Montana. Smithsonian Miscellaneous Collection (quarterly issue) number 50, June 27, 1907, pages 105-128, plates XI-XIV.

Identifications of fossil plants from the Matanuska Basin, Alaska. In Paige and Knopf, United States Geological Survey, Bulletin 327, 1907, page 26.

1908. Description of a fossil liverwort from the Fort Union beds of Montana. Proceedings, United States National Museum, volume XXXV, 1908, pages 157-159, plate XXV.

List of Lance plants from near Yule, Billings County, North Dakota. In A. G. Leonard, Geological Survey of North Dakota, Fifth Biennial Report, 1907-1908 [1908], page 49.

List of Fort Union plants from Bowman and Billings counties, North Dakota. In A. G. Leonard, Geological Survey of North Dakota, Fifth Biennial Report, 1907-1908 [1908], page 62.

Identifications of fossil plants from Hamilton Bay and Port Camden, Alaska. In F. E. and C. W. Wright, United States Geological Survey, Bulletin 347, 1908, pages 59, 60.

Identifications of fossil plants from the Rangely oil district, Rio Blanco County, Colorado. In H. S. Gale, United States Geological Survey, Bulletin 350, 1908, page 25.

Identification of fossil plants from the Controller Bay region, Alaska. In G. C. Martin, United States Geological Survey, Bulletin 335, 1908, pages 29, 34, 35, 39.

Report on fossil plants from the Foreman beds (Jurassic) of the Taylorville region, California. In J. S. Diller, United States Geological Survey, Bulletin 353, 1908, page 55.

Identification of Jurassic plants. In J. S. Diller, Bulletin of the Geological Society of America, volume 19, 1908, pages 367-402.

Report on fossil plants. In J. S. Diller, Bulletin of the Geological Society of America, volume 19, 1908, pages 384-386.

1909. The stratigraphic relations and paleontology of the "Hell Creek beds," "Ceratops beds" and equivalents, and their reference to the Fort Union formation. Proceedings, Washington Academy of Science, volume XI, 1909, pages 179-238.

Birds of the World. A popular account. Henry Holt & Co., New York, 1909, pages i-vii, 1-873.

Lists of plants from Dakota sandstone and Mesaverde formations in Washington. In G. B. Richardson, United States Geological Survey, Bulletin 371, 1909, pages 14, 17, 18.

1910. The Jurassic age of the "Jurassic flora of Oregon." American Journal of Science, volume XXX, July, 1910, pages 33-64.

Biologic principles of paleogeography. Popular Science Monthly, volume 76, 1910, pages 601-603.

Evidences of paleobotany as to geological climate. (With David White.) Science, new series, volume XXXI, 1910, page 759.

Succession and range of Mesozoic and Tertiary floras. Journal of Geology, volume XVIII, February-March, 1910, pages 105-116.

The climate of North America in later glacial and subsequent postglacial time. International Geological Congress, XI, Stockholm, Die Veränderungen des Klimas seit dem Maximum der letzten Eiszeit, 1910, pages 367-369.

Descriptions of fossil plants from the Mesozoic and Cenozoic of North America. I. 1, Two new fossil chain ferns (*Woodwardia*) from Oregon and Wyoming; 2, A new name for *Davallia tenuifolia* Swartz, as identified by Dawson, and *Asplenium tenerum* Lesquereux. Smithsonian Miscellaneous Collections, volume 52 (quarterly issue), part 4, 1910, 189-196, plates LXIII, LXIV.

Lance plants from Moreau Rim, South Dakota. In T. W. Stanton, American Journal of Science, volume 30, 1910, page 176.

1911. Flora of the auriferous gravels of California. In W. Lindgren, United States Geological Survey, Professional Paper 73, 1911, pages 57-64.

The study of fossil ferns. American Fern Journal, volume 1, number 5, July, 1911, pages 105-110.

Further data on the stratigraphic position of the Lance formation ("Ceratops beds"). Journal of Geology, volume XIX, May-June, 1911, pages 358-376; Washington Academy of Science Journal, volume 1, 1911, pages 105-110.

Remarks on the fossil turtles accredited to the Judith River formation. Proceedings, Washington Academy of Science, volume XIII, August 15, 1911, pages 51-65.

Where are the Laramie dinosaurs? Science, new series, volume XXXIV, September 8, 1911, pages 319, 320.

Description of two new fossil figs from Wyoming and Montana. Bulletin of the Torrey Botanical Club, volume 38, 1911, pages 389-392.

List of Lance plants from western North Dakota. In A. G. Leonard, Journal of Geology, volume 19, 1911, page 528.

Lists of Fort Union plants from western North Dakota. In A. G. Leonard, Journal of Geology, volume 19, 1911, pages 541, 542.

The correct technical name for the "dragon tree" of the Kentish Rag. Geological Magazine, decade V, volume 8, 1911, pages 467-468.

1912. Fossil plants of the coal fields of northern and central New Mexico. In W. T. Lee, Bulletin of the Geological Society of America, volume 23, 1912, pages 571-688.

Fossil plants from Grand Mesa region of Colorado. In W. T. Lee, United States Geological Survey, Bulletin 510, 1912, pages 39-47.

Lists of plants from the Lance formation near Glendive, Montana. In W. R. Calvert, United States Geological Survey, Bulletin 471, 1912, pages 13, 16.

Lists of Denver plants in Dawson arkose. In G. B. Richardson, Bulletin of the Geological Society of America, volume 23, 1912, pages 273, 274.

Memoir of W J McGee. Bulletin of the Geological Society of America, volume 24, 1912, pages 18-29, portrait.

1913. The fossil forests of Arizona. American Forestry, volume 19, 1913, pages 208-218, figures in text.

Description of a new fossil fern of the genus *Gleichenia* from the Upper Cretaceous of Wyoming. United States National Museum Proceedings, volume 45, 1913, pages 555-558, plate XLVI.

Results of a paleobotanical study of the coal-bearing rocks of the Raton Mesa region of Colorado and New Mexico. American Journal of Science, volume 35, 1913, pages 526-530.

The relations of paleobotany to geology. American Naturalist, volume 46, 1912. Reprinted in Smithsonian Report for 1912 [1913], pages 353-358.

1914. Report on fossil plants collected near Eugene, Oregon. In C. W. Washburne, United States Geological Survey, Bulletin 590, 1914, page 38.

The Jurassic flora of Cape Lisburne, Alaska. United States Geological Survey, Professional Paper 85-*d*, 1914, pages 39-64, plates V-VIII.

Fossil forests of the Yellowstone National Park. Department of the Interior, Office of the Secretary, 1914, 31 pages, 16 figures.

Cretaceous-Tertiary boundary in the Rocky Mountain region. Bulletin of the Geological Society of America, volume 25, 1914, pages 325-340.

1915. Description of a new fossil fern from the Judith River formation of Montana. Torreya, volume 15, 1915, pages 67-70, figures 1-5.

Seed-bearing ferns. American Fern Journal, volume 5, 1915, pages 83-87.

1916. Notes on two conifers from the Pleistocene Rancho La Brea asphalt deposits near Los Angeles, California. Washington Academy of Science Journal, volume 6, 1916, pages 85, 86.

Note on a recent discovery of fossil plants in the Morrison formation. Washington Academy of Science Journal, volume 6, 1916, pages 180, 181.

The flora of the Fox Hills sandstone. United States Geological Survey, Professional Paper 98-*h*, 1916, pages 85-93, plates XV-XVIII.

Contributions to the geology and paleontology of San Juan County, New Mexico; 4 flora of the Fruitland and Kirtland formations. United States Geological Survey, Professional Paper 98, 1916, pages 327-353.

A review of the fossil plants in the United States National Museum from the Florissant lake beds at Florissant, Colorado, with descriptions of new species and list of type specimens. United States National Museum Proceedings, volume 51, 1916, pages 241-297.

A Lower Jurassic flora from the upper Matanuska Valley, Alaska. United States National Museum Proceedings, volume 51, 1916, pages 451-460.

Principles governing the use of fossil plants in geologic correlation. Bulletin of the Geological Society of America, volume 27, 1916, pages 525-530.

A new fossil *Selaginella* from the Lower Tertiary of Montana. Torreya, volume 16, 1916, pages 201-204.

In E. W. Berry. The Upper Cretaceous deposits of Maryland. Upper Cretaceous floras of the world. Maryland Geological Survey, 1916, pages 235-240.

1917. A fossil flora from the Frontier formation of southwestern Wyoming. United States Geological Survey, Professional Paper 108, 1917, pages 73-107, plates 27-39.

Fossil floras of the Vermejo and Raton formations of Colorado and New Mexico. United States Geological Survey, Professional Paper 101, 1917, pages 223-435.

1918. Relations between the Mesozoic floras of North and South America. Bulletin of the Geological Society of America, volume 29, 1918, pages 607-614.

1919. Description of a supposed new fossil species of maize from Peru. Washington Academy of Science Journal, volume 9, 1919, pages 134-136, one text figure.

A catalogue of the Mesozoic and Cenozoic plants of North America. United States Geological Survey, Bulletin 696, 1919, 815 pages.

Evolution of geologic climates. Bulletin of the Geological Society of America, volume 30, number 4, 1919, pages 499-566.

A dicotyledonous flora in the type section of the Morrison formation. American Journal of Science, fourth series, volume 49, March, 1919, pages 189-194.

1921. Are the Lance and Fort Union formations of Mesozoic time? Science, new series, volume 53, April 1, 1921, pages 307-308.

Criteria for determination of climate by means of fossil plants. Bulletin of the Geological Society of America, volume 32, number 3, September 1, 1921, pages 353-358.

Further remarks on the evolution of geologic climates. American Journal of Science, fifth series, volume 2, October, 1921, pages 187-196.

1922. The Laramie flora of the Denver Basin, with a review of the Laramie problem. United States Geological Survey, Professional Paper 130, 1922, 175 pages, 1 figure, 38 plates.

Floral continuity in Lance and Fort Union sections. Pan-American Geologist, volume 37, number 1, February, 1922, pages 67-68.

A fossil dogwood flower [*Cornus speciosissima*, Converse County, Wyoming.] American Journal of Science, fifth series, volume 4, August, 1922, pages 136-138, two figures.

1923. Revision of the flora of the Green River formation, with descriptions of new species. United States Geological Survey, Professional Paper 131, 1923, pages 133-182, plates XXXVI-XL.

Fossil plants from the Tertiary lake beds of south-central Colorado. United States Geological Survey, Professional Paper 131, 1923, pages 183-197, plates XLI-XLIV.

1924. Flora of the Animas formation. United States Geological Survey, Professional Paper 134, volume IV, 1924, 117 pages, 19 plates. (With J. B. Reeside, Jr.)

1925. The possible origin of the Angiosperms. Science, volume 161, 1925, pages 563-570.

Flora of the Latah formation of Spokane, Washington, and Coeur d'Alene, Idaho (with a note on the fossil diatom deposits at Spokane, Washington, by Albert Mann.) United States Geological Survey, Professional Paper 140, 1925, pages 17-81, plates VIII-XXXI.

MEMORIAL OF WILLIS THOMAS LEE [1]

BY WILLIAM C. ALDEN

Sixty-two years ago, on December 24, 1864, there was born to John C. and Louesa J. Lee, on a farm among the hills near the village of Brooklyn, Susquehanna County, Pennsylvania, a son who was destined to become one of the well known and leading geologists of this country. This son, Willis Thomas Lee, was next to the youngest of the family group.

[1] Manuscript received by the Secretary of the Society January 21, 1927.

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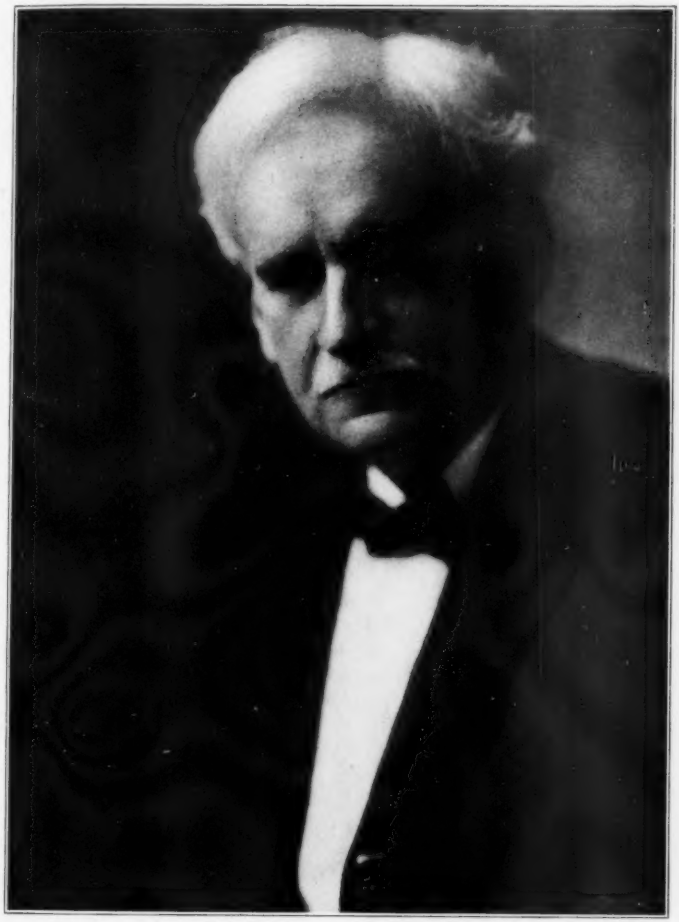
The writer is indebted to Mrs. Mary Ingham Lee and her daughter, Miss Elizabeth Lee, and to several of Dr. Lee's associates on the Geological Survey, for much assistance in preparing this sketch, and also to men in other government bureaus for data. Files and publications of the Federal Survey have been drawn upon freely for information and for quotations, some of which may not be specifically credited to their writers.



Willis T. Lee

which included two boys and four girls. Nothing in particular distinguished him from the average country boy of that day, and, like many other boys whose fathers wanted them to be farmers, he disliked farm life and had no desire to be a farmer. At times, as he became older, he worked as a carpenter, or did anything else he could find to do, and with the funds so secured he hired another young man to take his place on the farm.

The turning point in his life appears to have come as a sort of inspiration on seeing some crude representations of extinct animals and ancient landscapes at the hands of one who has since become an honored member of this Society, Herman L. Fairchild.

In his posthumous volume, "Stories in Stone" (page 13), but recently come from the press, Doctor Lee wrote as follows regarding this inspiration:[2]

"Years ago, in the little Pennsylvania town where the first years of my life were spent, entertainments were rare, movies had not been invented, and good stereopticon pictures were unknown to me. But one boy from that town had chosen to be a teacher of geology. He had obtained what we then called a magic lantern, a crude apparatus for projecting pictures onto a screen by means of light from a kerosene lamp. The lantern would be laughed at today, and the slides—what crudities they were! But to me they were wonderful!

"Each vacation when the geologist came home the magic lantern came with him and the pictures were exhibited. I counted the months, the weeks, the days from vacation to vacation, and the hours of the day until finally I sat in open-eyed wonder gazing at those imperfect representations of extinct animals and ancient landscapes. My imagination was stirred profoundly and there settled upon me a determination to know something of the wonders of this old earth of ours."

Not until he was 21 years of age, however, did he receive any other education than that afforded by the local common school and by reading. When he became of age he felt that he was no longer needed on the farm, and, borrowing money on his life insurance policy, he went to Wyoming Seminary, at Kingston near Wilkesbarre, Pennsylvania. In this preparatory school, which was of about the same grade as a high school, he spent four years, and here he met the young woman, Miss Mary Ingham, of Mehoopany, Pennsylvania, who was later to become his wife. He drank eagerly at this fountain of learning, for his thirst was insatiable, and he felt keenly his backwardness as compared with the other students, most of whom were several years younger than he. Having no funds, he pluckily proceeded to pay his own way by working outside of study hours,

[2] This and other quotations from "Stories in Stone" are used with the permission of D. Van Nostrand Co., publishers, 8 Warren street, New York City.

but this necessitated much hard work and left him little time to participate in the various student activities, which he regretted very much. Vacations were also given up to work.

In the spring of 1890 both he and Miss Ingham were graduated from Wyoming Seminary. For ten years thereafter their lives flowed in different channels, but the well-established friendship was maintained through correspondence and occasional visits. On Willis's advice and assistance, his sister Alice also attended Wyoming Seminary. Later she was graduated from Syracuse University, taught for a period of years in Cazenovia Seminary, New York, and became a writer of short stories. His sisters, Evalyn and Alice, and his brother Edward survive him.

University Days

In the fall of 1890, when nearly 26 years of age, Mr. Lee entered Wesleyan University at Middletown, Connecticut. Here also he worked his way as far as possible, supplementing the returns of his labors with borrowed money. He tended the furnace and did other work in return for a room in the home of two dear old ladies in Middletown, for whom he long afterwards retained a deep affection. He also served as steward in the house of Phi Nu Theta Fraternity, of which he was a member, in return for table board, and, having a good voice and an ability to sing, he gained a place on the university glee club.

At Wesleyan University he took a general course, but he became so greatly interested in chemistry that he hoped later to specialize in that science. In the geology class he came under the instruction of Prof. William North Rice, an inspiring teacher and one of the most able and best beloved of American geologists. Professor Rice undoubtedly had a great influence on his subsequent career, and for this great man Mr. Lee ever afterwards had the highest admiration and respect. In the spring of 1894 Mr. Lee received the degree of Bachelor of Arts from Wesleyan University, and later, in 1898, the degree of Master of Science was conferred on the basis of work done *in absentia*.

After graduation, the first employment offered was in the classroom, and he spent the school year 1894-1895 in teaching chemistry and botany in Rhode Island College of Agriculture and Mechanical Arts, Kingston, Rhode Island. On the completion of this work he was offered the professorship of geology and biology at Denver University, under the presidency of Dr. W. F. McDowell (now Bishop of the Methodist Episcopal Church). This he accepted and went to Denver in the fall of 1895. He had done no graduate work in geology, but he had taken a general course

in this subject and had enough self-confidence to believe that he could carry on the work. He therefore proceeded to study hard in order to keep ahead of his classes, and he was able to "put it over" satisfactorily, and continued in this position until the spring of 1898. While there he was leader of the university glee club and conducted it on some local concert tours. He also took many trips into the mountains, especially during vacations, and the call of the Rockies, together with his growing love of the works of Nature, made so strong an appeal that he decided to specialize in geology.

In order to prepare for this, his life work, he went to the University of Chicago in the autumn of 1898 as a fellow in geology. There he pursued graduate studies for two years under T. C. Chamberlin, R. D. Salisbury, J. P. Iddings, Stuart Weller, and their associates.

In June, 1900, Mr. Lee married Miss Mary Ingham, and together they went to Boulder, Colorado, where he delivered a series of lectures on geology at the summer session of the Boulder Chautauqua Association. Here he wrote two papers on the local geology (2 and 3[3]). Following this he accepted the position of principal of high school at Trinidad, Colorado, which position he held until the spring of 1902, and here his daughter Elizabeth was born. While at Trinidad he carried on, with the assistance of T. A. Pierce, certain studies of the Morrison formation in that region. The call of geology was insistent, and in the fall of 1902 Mr. Lee removed his family to Baltimore and entered Johns Hopkins University for further graduate studies under Dr. William B. Clark and his associates. In March, 1903, however, an attack of typhoid fever forced him to leave school. Later, in 1912, after he had fulfilled certain requirements, this university conferred on him the degree of Doctor of Philosophy.

Work on the United States Geological Survey

While convalescent, in May, 1903, Mr. Lee visited the offices of the United States Geological Survey in Washington and learned that a man was wanted to go West with N. H. Darton, who had recently been placed in charge of the newly organized Western Section of the Hydrographic Branch under the direction of F. H. Newell. Mr. Darton was instructed to investigate the underground water supplies in the so-called reclamation States and Texas. Mr. Lee, having passed the Civil Service examination, was offered the opportunity to take part in this work as a field assistant and accepted. Others assigned to the section were W. C. Men-

[3] Figures refer to papers listed in the bibliography which follows.

denhall and G. B. Richardson, assistant geologists, and C. A. Fisher, field assistant. Pale and weakened by his recent illness, Mr. Lee, on his first assignment, showed little promise of the vigor which he displayed in the following years of exploration of the mountains, plateaus, and canyons of the West and Southwest. From this time until his death, twenty-three years later, in 1926, with the exception of a few periods of leave, he was engaged on the work of the Federal Survey.

Mr. Lee removed his family to Phœnix, Arizona, in the spring of 1903 and began, in the Gila River Valley, his studies of the Southwest, and from this work came the first of his official reports, "The underground waters of Gila River Valley, Arizona" (11). The area studied comprised that part of Gila Valley in the Pima Indian Reservation below Florence, and the investigation was to determine how much underground water was available for irrigation by pumping. The Indians had been deprived of water by diversion of the stream by the white settlers farther up the valley, causing a reduction of 50 per cent in the area of cultivated land in the reservation. Mr. Lee's study showed that the volume of underground water flow was greater than the estimated needs of the Indians, and he concluded that under proper supervision this water could be pumped at sufficiently low cost to render the Indians moderately prosperous. The report on the Gila Valley was followed by a similar report on study of the Salt River Valley (12). This paper included a chapter on the geology and physiography of the region and a résumé of important facts with interesting deductions. The search for a supply of water below the surface led to a careful study of the materials filling the valleys, and Mr. Lee found evidence that the valley fill, which reaches a maximum of 1,300 feet, represents at least two periods of filling, with an intervening time of erosion. The geologic age of the formations could not be determined accurately because of lack of fossils, but from other lines of evidence he concluded that the older fill probably represented the base of the Quaternary. He, however, recognized the possibility that it might be of Tertiary age and only the upper few hundred feet be of Quaternary age. From the similarity of conditions here and elsewhere he concluded that the observed phenomena could not be the result of climatic changes alone, but where due to regional elevation and depression of the land.

In 1903-1904 Mr. Lee studied the valley of Colorado River from the mouth of the Grand Canyon to Yuma. The opportunity for a trip down the river by boat he always considered as most fortunate, for it enabled him to observe the ability of running water to carry great loads of gravel

and boulders. This was "indelibly impressed" on his mind, as shown by the following quotation from "Stories in Stone" (pages 40-41):

"While I was at the mouth of the canyon, where the river emerges like a huge mill race from between the mile-high walls, the water began to rise and to increase the velocity of its flow. This increase disturbed the boulders that had lodged along the river's course and made them resume their interrupted journey toward the sea. The river here is perhaps 300 feet wide and 25 feet deep and is confined in a trough of solid rock. The gravel and boulders are washed through this trough with terrific force to find temporary lodgment in the more open spaces below the mouth of the canyon.

"My attention was attracted by a peculiar muffled rumbling, which I did not at first understand. My thought at once turned to the sudden floods in Arizona, with which I was familiar, where the dry sandy bed of a wash may suddenly and without obvious cause become a raging torrent; the cause, a sudden downpour of rain at some distant point hours before, may have been forgotten or may have been beyond the range of vision.

"I did not then know the Colorado as well as I know it now, and, fearing a sudden rise in the water, my boatman hastily secured the boat and we climbed up the banks for safety. I made my way along a shelf of rock into a narrow part of the gorge and there discovered the cause of our alarm. The swift current was rolling boulders through the rock trough.

"My shelf of rock was perhaps 10 feet above the water and the boulders in the turbid flood below were crashing and grinding against the rock walls. Reason told me I was perfectly safe—that thousands of floods had rolled boulders through the trough without injury to the shelf on which I stood. But of what use is reason at such a time? Precaution (or perhaps it should be called fear) argued that 'some time this shelf will fall, and maybe that time is now!' A score of reasons were marshaled why I should leave that particular shelf forthwith."

In the course of this work in the Colorado Valley Mr. Lee also examined most of the adjacent valleys and mountain ranges. The geological results of this study were presented in abstract before the Geological Society of America (15), of which Society he had become a fellow in 1903, and they were later incorporated in Bulletin 352 of the United States Geological Survey (25). This paper was an important contribution to the geology of a large and little-known region.

In 1904 a reconnaissance study of the ground-water of Owens Valley, California, afforded opportunity for a much-enjoyed trip to Mount Whitney, Mount Lyell, the Yosemite Valley, and adjacent parts of the High Sierras. He wrote (13 and 14):

"To judge from present knowledge of the two lakes [Mono and Owens lakes] and of Mount Lyell Glacier, it is evident that the popular belief in a diminution of rainfall in the vicinity of Owens Valley for the last ten years is not supported by the facts, and that if any change of climate is in progress it is towards a more humid rather than a more arid climate."

His observations also tended to support the view that the main uplift of the Sierra block occurred at the close of the Tertiary period.

From study of the ground-waters of Arizona, Mr. Lee was transferred to the Rio Grande Valley and other parts of New Mexico, where he carried on an investigation (17 and 20). Here he became interested in the problem of the "Red Beds" (21 and 27) and also in that of the remarkably well preserved volcanic cones of this region. Concerning the latter, he reached the following conclusions (22):

"The observed facts all point to the hypothesis of volcanic explosion as giving the most rational explanation of the Afton craters. It is, furthermore, probable that the explosions were caused by the formation of steam generated by lava that was forced into the water-saturated sands, but that failed to reach the surface. The probable presence of this lava, still retaining its heat in some measure, is indicated by the occurrence of the warm well water in the Kilburn Crater."

Mr. Lee recognized Capulin Mountain, in northeastern New Mexico, as a magnificent example of a recently extinct volcano (39), and recommended that it be made a national monument, under control of the National Park Service. Later, in August, 1916, Lee's recommendation was followed and a tract of 680 acres, including this mountain, was set aside by presidential proclamation and designated the Capulin Mountain National Monument.

The last one of his hydrographic studies was in Beaver Valley, Utah (24), and included part of the narrow southern end of the Lake Bonneville Basin. In this connection he also made a brief examination and report on the Cove Creek, Utah, sulphur beds (18). By June 30, 1906, the Reclamation Service and the Geological Survey had become entirely separate, excepting that both were under the same director, Dr. C. D. Walcott. This change involved the discontinuance of Mr. Lee's search for ground-water supplies, and he was transferred to another line of work in the Geological Survey.

Classification of Coal Lands

In 1905 the Chief Geologist of the Geological Survey began to foresee the great demand that was likely to be made in the near future for the classification and appraisal of the coal lands of the West whose title still rested in the Government. He determined to anticipate this demand, and so in 1905 several geologists, under the direction of Marius R. Campbell, were sent into the Western States to map and study the geology of the coal fields, to determine the quality of the coal in these fields, and to gather data for an estimate of the tonnage of coal that they might be

expected to produce. Mr. Lee was not particularly interested in the economic questions involved in this work, but, in the many years that he followed it, it gave him an opportunity to carry on the stratigraphic studies and age determinations in which he was vitally interested.

In the years 1905 and 1906 Lee examined several small fields in central and southern New Mexico and Utah (36, 38, and 41), but his first important work was done in 1907, in the Grand Mesa coal field of western Colorado. This field had never before been studied in detail, and Lee's work was of great value in giving a comprehensive description of the Cretaceous coal-bearing formation. Before the work was done this formation had been regarded as a unit corresponding to the Mesaverde formation of the southwestern part of the State, but Lee found that it really consisted of two parts which differ from one another, not only in the character of the rocks but also in the quality of the coals they contain. Recently J. B. Reeside, Jr., has shown that the lower part only is the equivalent of the type Mesaverde, and that the upper part is probably much younger.

Mr. Lee finally carried his work eastward until he connected it with the Anthracite and Crested Butte area north of the city of Gunnison, thus bridging a very serious break in the geologic mapping. The results of this work are embodied in a preliminary report (29 and 43) and a complete report covering the entire area, entitled "Coal fields of Grand Mesa and the West Elk Mountains (37).

Already Lee had become an excellent photographer. He generally followed the maxim that a photograph that was worth taking at all was worth taking well, and as a consequence the files of the Federal Survey contain hundreds of excellent views which he took, many of which have found their way into official reports, textbooks, magazines, and other publications. In the preparation of this biographical sketch the writer has found it most interesting to look over Lee's books of photographs and so in imagination to accompany him through several fields of exploration. Some views show him working under difficulties at high altitudes, among great banks of snow covering the coal beds of Anthracite Mesa, Colorado, late in June, 1909, where the use of gloves and mosquito bar was necessary for the protection against the great number of mosquitoes.

The Problem of the Cretaceous-Tertiary Boundary

An important piece of work had already been begun by Mr. Lee at the east front of the Rocky Mountains, in the Raton, New Mexico, coal field (30, 34, and 35), and this study was continued over several years. A

minor phase of this which may be mentioned was the examination of an interesting occurrence of graphite near Raton, due to the intrusion of igneous material into the coal-bearing rocks (32 and 40). The geological importance of the work in the Raton field, aside from the examination and mapping of the coal beds, lay in its bearing on the problem of the position of the boundary between the Cretaceous and Tertiary systems. In this study Mr. Lee was closely associated with the late F. H. Knowlton, who interpreted the evidence furnished by the fossil flora as distinguished from that furnished by the vertebrate and invertebrate faunas. This problem was probably the most important to which Mr. Lee had thus far given his attention, and its study brought him into conference with many of the leading geologists of the country. The results of the study are embodied in two papers: "Geology of the Raton Mesa and other regions in Colorado and New Mexico," by Willis T. Lee, and "Fossil floras of the Vermejo and Raton formations of Colorado and New Mexico," by F. H. Knowlton (49), published together in 1917 as Professional Paper 101; and the Raton-Brilliant-Koehler (New Mexico-Colorado) folio of the United States Geological Atlas, by W. T. Lee (61). Lee and Knowlton were familiar with the Mesozoic and Lower Tertiary formations on both sides of the Rocky Mountains and they had been much in conference and in discussion with T. W. Stanton and others familiar with the faunas of these same formations.

This discussion of the Cretaceous-Tertiary boundary was by no means initiated by Lee's studies. It had been going on for some time before his hat was thrown into the ring. The controversy was very largely carried on within the precincts of the Geological Survey, but the problem was discussed considerably in scientific periodicals and in the geological societies of Washington and America. It penetrated to college and university classrooms and influenced, more or less, the authors of geologic textbooks. In preparing this sketch, within six months after the death of Doctor Lee and but a short time after Doctor Knowlton laid aside his geologic studies for an eternal rest, the present writer is not disposed to pass judgment on the importance of their contributions, even were he competent to do so. Suffice it to say that both men carefully collected, critically studied, and ably presented data bearing on this important problem, and many less familiar with the field evidence have profited thereby. As the result of these and later studies, Doctor Lee came to be recognized as one of the leading authorities on the geologic history and structure of the southern Rocky Mountains.

Generally speaking, it was found that the Raton and Vermejo formations, as they were designated, were separated by an important uncon-

formity, and that the plant remains of the Raton above the unconformity were of Tertiary types, while those of the Vermejo below the unconformity were of Cretaceous types. Collections made by Lee, Richardson, Saint John, and others, from the fossil floras of the formations in question, were stated by Knowlton (49, page 227) to be "the most extensive and in many respects the finest material thus far brought together from any horizon within the Rocky Mountain areas." The flora of the Vermejo formation comprised 108 species, presenting a "remarkably distinct and characteristic aggregation of plant forms." Only four species were found to cross the boundary. There were found to be "marked and striking differences" between the two floras. Before this investigation the coal-bearing rocks of the Raton Mesa region, both above and below the unconformity, were regarded as belonging to the Laramie formation. Following this study, the Cretaceous-Tertiary boundary in this region has been drawn between the Vermejo and Raton formations in the official classification of the Geological Survey and by many other geologists. The question as to what are the correlatives of the Raton formation in other fields farther north yet remains open.

The Overland Guidebook and Rocky Mountain National Park

When, in 1914, the preparation of a series of geologic guidebooks of the western United States was undertaken by the Geological Survey in anticipation of the large tourist travel to the Panama-Pacific Exposition, to Doctor Lee was assigned the preparation of the description of the strip of country traversed by the Union Pacific Railway from Council Bluffs to Ogden. Many persons, including the present writer, have found this description (45), and also the others, very convenient, interesting, and valuable for perusal in connection with railway and automobile trips and geologic reconnaissance studies in the country described and also for office reference.

The desirable but difficult feat of presenting to the untrained general reader the results of scientific research in understandable and interesting form was attempted, with good success, in the Overland Guidebook and again in "The geologic story of Rocky Mountain National Park" (50), which Mr. Lee as a geologist of the Federal Survey, prepared at the request of the National Park Service after a careful reconnaissance study of the features of the park. It was published by the Park Service in 1917 as a finely illustrated booklet (50).[4] This booklet is stated by Supt. Roger W. Toll, in a letter to Mr. Lee, to be a popular one with visitors to the park.

[4] The total number of visitors to this park in 1926 was 225,027.

Similar efforts to popularize the results of scientific study were made by Mr. Lee in stereopticon lectures given before numerous schools, churches, clubs, and societies. These were generally based on his own field observations in many parts of the country in the course of his work for the Federal Survey and on extensive reading and study of the work of other scientists; so also were his numerous notes for Science Service, magazine articles, and the posthumous volume, "Stories in Stone." From the examination of Rocky Mountain National Park came also a physiographic paper treating of the peneplains of the Front Range (62).

Stratigraphic Correlation Studies in the West

While the work in the Raton Mesa region was in progress reconnaissance studies were extended by Mr. Lee to the north and to the south for the purpose of determining the age correlations of the coal-bearing formations of the southern part of the Rocky Mountain region and the physical conditions under which they were deposited. Some of these studies were made in company with T. W. Stanton.

The curtailment of appropriations for scientific work for some time following the World War resulted in many changes of the personnel of the Federal Survey and the field investigations which could be undertaken. This was a period of great uncertainty with scientific men in the Government service—geologists and others—and Doctor Lee was no exception. Late in 1918 he was granted leave of absence (January 1 to June 10, 1919) from the Federal Survey in order to accept, for the balance of the year, the position as head of the Department of Geology and Director of the School of Engineering Geology at the University of Oklahoma, and he removed the family residence to Norman, Oklahoma, for that purpose. Later, after returning to the Survey, he was again granted leave (November 1, 1919, to January 16, 1920) to deliver lectures on geology at Yale University.

Doctor Lee's heart was, however, in the work of the Geological Survey, especially in the broader scientific phases, for which he felt himself best adapted. Until opportunity for such work was presented, his attention was given to working up material in hand and to such field assignments as were open, such, for example, as cooperative work on the Atlantic Coastal Plain in 1920-1921, for incorporation in a geographic handbook of Virginia (which now awaits publication by the Virginia Geological Survey). In June, 1921, he took up a field study of the formations exposed along the foothills of the Rocky Mountains in northern Colorado, assisted by H. S. Cave, and fossils bearing on the correlations of the

formations were collected for study by the paleontologists. Particular attention was paid to accuracy of measurement of the formations, with the object of determining more precisely the stratigraphic relations of the sands productive of oil in other regions. The studies were continued northward, along the eastern front of the Laramie Range, with a view to determining the extent and thickness of the oil-bearing strata of Wyoming, and in 1922 they were extended into the central part of the State, along the east front of the Wind River Mountains and into the Big Horn Basin.

This work of correlation was not all clear and easy sailing, and Lee's proposals had to be supported by good evidence and vigorously defended if their acceptance by his colleagues within and without the Survey was to be obtained. So important, however, was it that correlations in the field should be attempted that Doctor Lee's stratigraphic studies were extended on northward in 1923-1924 to the vicinity of Roundup, on the Musselshell River, and along the mountain borders to the north end of the Little Belt Mountains, Montana, and into Yellowstone National Park.

At the request of the writer, H. D. Miser has prepared the following statement concerning these correlation studies:

"A study of the Paleozoic and Mesozoic rocks of parts of Colorado, Wyoming, and Montana was begun in 1921 by Doctor Lee and continued through 1923. The results of the study are presented by him in the Geological Survey's Professional Paper 149, which is now in press. This study was one of the most comprehensive projects undertaken and carried out by him, and its object was not merely the acquiring of information on difficult correlation problems, but was primarily a search for information of assistance to those engaged in the recovery of oil and gas in the three States.

"Many parts of the regions that were studied by Doctor Lee had been examined in former years by numerous geologists. In Professional Paper 149 he has harmonized, so far as possible, their reports and has shown how the variously named formations are related to one another. Among his most important conclusions are those with reference to a group of rocks for which he sponsored the name Dakota group. Concerning this group the two following paragraphs are abstracted from his report:

"'There is no single, definite, persistent, and easily recognized sandstone such as was formerly supposed to exist and was termed the Dakota sandstone. In its place there is a group of intimately related beds. Doubtless there are many overlapping lenses that differ slightly in age. The group as a whole is interpreted as the result of accumulation of sediments near the strandline of the advancing Cretaceous sea, and as such it differs in age from place to place by the length of time consumed by the advance of the strandline across the intervening distance. Whether this advance marks the beginning of Upper Cretaceous time remains to be determined.

"'Doctor Lee long maintained that the obvious time break between the

Morrison formation (regarded by him as Lower Cretaceous) and the overlying conglomerate of his Dakota group denotes a major unconformity. He also held that in the absence of any obvious unconformity within the assemblage of rocks which he would call Dakota group he was in favor of classing the entire group as Upper Cretaceous, although he included in it rocks that are in some areas usually classified as Lower Cretaceous.'"

The summer of 1925 found Doctor Lee back again working on stratigraphic correlation studies and coal land classification in western Colorado and southeastern Utah and northwestern New Mexico. This proved one of his most strenuous field seasons. The hard climbing and the excessive heat on the cliffs and in the canyons of this region left him so far exhausted that he felt as though he could never stand another such field season, and it finally proved to be his last in the West. A manuscript report on this work, entitled "Continuity of formations in western Colorado and eastern Utah," was prepared by Doctor Lee. This will probably not be issued as a separate publication, but will be incorporated with other data on this region.

Geography and Geology from Airplanes

While engaged in the investigations on the Atlantic Coastal Plain, Doctor Lee became greatly interested in the possibilities of the use of airplanes in geographic and geologic field studies, as well as in topographic and other mapping. Largely as the result of his initiative and through the active interest of Major J. W. Bagley, United States Army Engineering Corps, he became acquainted with officers of the Airplane Service, who gave the necessary authorization for making trial flights and for securing photographs. The first flight taken by Doctor Lee was for the purpose of testing the utility of the airplane for observing such country as parts of the Coastal Plain that are either inaccessible or accessible only with difficulty by ordinary methods. The results of this flight are given in a short paper, "Airplanes and geography," published in November, 1920, in the Geographical Review. A trip of 200 miles was taken over parts of eastern Virginia, including Hampton Roads, the Dismal Swamp, and James River Valley. Of the conditions under which this work was done, Doctor Lee wrote in the above article (57, page 310):

"This paper . . . is based on observations made possible by the cooperation of officials of the air services of the War and Navy departments. The assistance of Capt. Walter R. Lawson, operations officer, and Capt. Fred Place, director of the School of Aerial Photography, at Langley Field, is gratefully acknowledged. These officers placed at my disposal their entire collection of photographs, from which many were selected for illustration. . . . Some of the photographs used here were made by Captain Place for this particular

purpose. Captain Lawson also interested himself in the investigation and personally piloted me in flights in order to point out particularly good examples of submerged land forms which he had observed. Later, officials of the Navy Air Service at Washington, D. C., extended similar privileges, and I was able to obtain views of the underwater channels and drowned terraces of the Potomac."

From the remarkable visibility of features beneath shallow water as seen and as photographed from airplanes, he became greatly interested in the possibilities of their mapping and study. Further opportunities were afforded by flights along the Potomac River, along the New Jersey coast, and on Long Island in the vicinity of Mineola and Rockaway Beach. From these came the handsomely illustrated book, "The face of the earth as seen from the air," published in 1922 by the American Geographical Society (60).

Mr. Lee was in no sense a dare-devil, nor craving the experiences of a stunt flyer, nor wishing to do something out of the ordinary just to be sensational. These flights were not taken as joy rides but strictly as a scientific investigation under the auspices of the Federal Survey. He rarely had anything to say about the experiences of flying as such. Of course, considered as aviation feats, he realized they were not worth mentioning. It was only as the result of direct questioning that his curious friends got any statement at all, and then it was to say that there is about as much thrill in ordinary flying as in "sitting in a rocking chair on the front porch." He, however, went so far as to admit that his vital organs took a jump into his throat when the plane dropped suddenly from stable flying over land into a "hole in the air," where currents of lighter air were ascending from the warmed surface of a body of water. He tells, in "Stories in Stone" (pages 168-169) of his feeling while "looking a thunderstorm in the face." Many a reputable geologist or geographer has attempted field observations, and even assayed conclusions based on what he saw from the rear end of a Pullman or from a speeding automobile, but few had at that time tried to make such observations from a machine traversing the air at altitudes of a mile or more and at rates as high as 100 miles per hour. His observations were not, however, confined to these flights, but, besides taking many photographs himself and studying them, he eagerly searched the files of the Air Service, to which he was permitted access, and culled from them many characteristics and significant views illustrating different types of terranes, of rock exposures, and of submerged features as seen from the air. His aim was not so much to present results accomplished by himself as to arouse the interest of his scientific colleagues in the use of airplanes, which he believed would in

time become valuable aids in certain classes of geologic and geographic work. Much time was spent in conference with men competent to consider and to advise on technique and procedure, on what should be attempted, and on the interpretation of the results obtained. Papers were presented and talks were given before meetings of the Washington Academy of Sciences and the Geological Society of Washington, in one of which meetings foreign officers and officers of the Federal Service took part.

So far as known to the writer, no opportunity was offered for Doctor Lee to actually undertake any piece of geologic mapping by airplane. Airplane photography has, however, already been used by some of his colleagues as a valuable adjunct in geologic mapping, as distinguished from its wide use in topographic and other mapping. As such geologic and geographic use becomes more common, Doctor Lee will undoubtedly come to be recognized as one of the pioneers in its development in this country.

Carlsbad Cavern and other Caves

In 1923 Doctor Lee went to New Mexico to make an examination for the United States Reclamation Service of the site of a proposed storage reservoir for irrigation of the Pecos River Valley. The conditions which he found there are summarized as follows in his short paper, entitled "Erosion by solution and fill" (68, page 121):

"Pecos Valley, in southeastern New Mexico, is a succession of broad shallow depressions which can be attributed only in part to surface erosion. The chief cause of these basins is believed to be local subsidence due to the removal by solution of soluble rock near the surface.

"Through sink-holes the surface debris which in most other regions is removed by run-off is here carried into subterranean caverns. The water that washes the debris into the caverns dissolves the soluble rocks and forms other caverns, which are similarly filled later. The transfer of soluble material from below ground to the surface at some lower altitude and of surface waste to underground caverns is not unknown, but has not been sufficiently emphasized to make it a familiar process of erosion. In Pecos Valley it is a dominant process."

Study of the solution of the salt and gymsum-bearing rock formations of this basin led Doctor Lee to visit the great cavern, locally known as Bat Cave, in Guadalupe Mountains, west of Carlsbad, New Mexico, and he became very enthusiastic over what he found therein. He writes:[5]

"I came away full of enthusiasm, believing that I had seen the most marvelous underground realm that had ever come to light."

[5] W. T. Lee: Carlsbad Cavern, New Mexico (unpublished manuscript, 1926).

Securing numerous photographs, he brought them to Washington and set about arousing interest in organizing a scientific expedition to map and study the cavern in order to determine the mode of formation of its ornamental features and the possibility of its containing remains of prehistoric man. He considered this the most wonderful cavern in the United States and he made vigorous efforts to have it set apart as a national monument.

Robert A. Holley, after making a survey of parts of the cavern in 1923, to determine the exact location of the guano deposits for the General Land Office, had stated in his report that "the cavern is of such wonderful character as to be worthy to be established as a national monument." This was brought to the attention of the Director of the National Park Service, and when Doctor Lee learned of this recommendation he was much pleased and endorsed it heartily.

Lee's photographs and descriptions presented in conferences, in numerous talks illustrated by stereopticon, and in an article published in the National Geographic Magazine (67), together with representations made by others (see page 180), resulted in the issuance, October 25, 1923, of a presidential proclamation setting aside the land, including the greater part of the cavern, as Carlsbad Cave National Monument.[6]

Another result of the exploration and description of Carlsbad Cavern and its environs was the creation of a Texas State park, including the southern end of the high part of the Guadalupe Range adjacent to the Carlsbad Cave National Monument. Lee's photos and descriptions presented to a congressional committee were largely instrumental also in securing an appropriation for beginning work on improving the road and the entrance leading to Carlsbad Cavern and installing an electric plant for it. Doctor Lee's work in the Carlsbad Cavern attracted so much attention that through the influence of Dr. F. V. Coville, chairman of its Research Committee, the National Geographic Society decided to finance an expedition under the leadership of Doctor Lee to explore the great cavern, and for this purpose he was granted leave of absence from the Federal Survey for the year ending March 15, 1925. In order that possible complications due to divided authority might be avoided, the National Park Service appointed Doctor Lee as temporary custodian of the newly created national monument.

In the spring of 1924 Doctor Lee removed the family residence temporarily to Carlsbad, New Mexico, and, with the assistance of some local men and his son Dana and his daughter Elizabeth, set about the explora-

[6] In 1926 the number of visitors to this cavern totaled 10,904 persons.

tion. R. H. Runyan was granted leave of absence from the Topographic Branch of the Geological Survey to make the instrumental survey of the cavern, and Vernon Bailey, of the United States Biological Survey, was sent by the Department of Agriculture, in cooperation with the National Geographic Society, to study the bats and other animals of the cavern. Many representatives of the cave fauna were collected and turned over to several specialists for study. Paul Standley, botanist, also studied the plants of the vicinity.

Lee states (70, pages 302 and 312) that the work "was carried on under circumstances quite out of the ordinary. New methods had to be devised for the simplest operations." Moreover, as is evident from some of his descriptions, the exploration was not unattended with dangers. He writes:

> "On one occasion I lost my footing and slid down a beautifully terraced slope studded with lovely but sharp and unyielding crystals. The effect of this mishap remains with me in the form of impaired eyesight."

The present writer has not been privileged to visit Carlsbad Cavern, but he has greatly enjoyed looking over the remarkably fine collection of photographs, taken by artificial light, which Doctor Lee brought back. Besides the many fine views taken by Lee himself, numerous views were taken by Jacob Gayer, of the National Geographic Society; moving pictures were also taken by Mr. Bockhurst for the International News Reel Corporation while the exploration was going on, so that very many people have been thrilled by the great profusion, infinite variety, and marvelous beauty of the stalactites, stalagmites, and other natural adornments of this most wonderful of all known caverns. Doctor Lee states of some of the rooms (70, page 315):

> "The stalactites seem to push forward for attention, as if each were trying to say, 'Behold me! In this basal darkness I have waited 10,000 years for one admiring glance.'"

On the conclusion of his examination, which, however, left an unknown extent of the cavern yet unexplored, a second descriptive article was prepared and published in the National Geographic Magazine (70), and an illustrated lecture was given before the members of the Geographic Society, before the Washington meeting of the American Association for the Advancement of Science, and before many other audiences. Doctor Lee also prepared manuscript for a finely illustrated monograph which awaits publication.

After returning to his official work on the Geological Survey, there came to Doctor Lee, in May, 1925, an opportunity to make further cave

examinations. At the request of Hon. Maurice H. Thatcher (Member of Congress from Kentucky), and under the joint auspices of the Geological Survey and a commission of five men appointed by Dr. Hubert Work, Secretary of the Interior, Doctor Lee spent a month in the spring of 1925 in the vicinity of Mammoth Cave, Kentucky, for the purpose of examining several caverns, this being one of the places urged as possible national parks. The results of this visit were embodied in a well illustrated manuscript (as yet unpublished) entitled "A visit to Mammoth Cave region, Kentucky."

In the Geographical Review for January, 1926, he gave a description of an ice cave 50 miles southeast of Gallup, New Mexico. Of the origin of the ice he wrote in part (71, pages 58-59):

"The occurrence of ice formed in caves has given rise to much speculation and in some instances to wild conjecture. However, one need not look for extraordinary causes in explanation of the ice, nor is it necessary to appeal to chemical changes, exhalations of gas, or other rare phenomena. The ordinary changes in weather and the well-known characteristics of scoriaceous basalt appear to be quite sufficient to account for the ice in our ice cave, though no extended observations were made in it. . . .

"The banding of the ice in the cave suggests a possibility of working out a chronology. The mass is made up of layers of ice. Each layer may represent a year's accumulation or it may represent a climatic cycle. This could probably be determined by careful observation. It is not impossible that the climatic changes recorded in the ice might supplement the chronology obtained by studying the growth of trees. The large pine trees of this region offer an attractive start for such a comparison."

In all his cavern studies, Doctor Lee was not content to photograph and describe the features, wonderful as they are; but, inspired with the scientific spirit, he was eager to find out the explanation of how and when these things came to be as they now are. He was always also looking for and hoping to find relics of prehistoric peoples and of extinct animals, so as to extend the geological and archeological knowledge of America. From his own experiences in exploration and in searching the literature for information, he soon realized that, with few exceptions, the examination of American caverns and their contents had scarcely been begun. Here, then, it seemed, was a field ripe for the harvest and awaiting only an interested scientist and the provision of funds to afford a rich return in geological and archeological material. One of the last things he did, in May, 1926, just a month before his death, was to prepare for the Chairman of the Division of Geology and Geography of the National Research Council an outline of desirable explorations of American caverns, indicating some of the information needed, some regions where it was likely to be found, and a provisional plan for a proposed exploration.

The same month Doctor Lee was sent, as one well acquainted with cavernous limestone formations, to examine the site of a proposed reservoir dam near Clifton Forge, Virginia. While on this trip he took the opportunity to visit Massanutten Caverns, near Harrisonburg, Virginia, and it was while examining certain important cave deposits there that he was taken very ill.

Closing Days and Fraternal Relations

From Harrisonburg, Doctor Lee was brought to his home in Washington, D. C. While on his sick bed and evidently realizing his precarious condition, he sent for Dr. J. W. Gidley, of the United States National Museum, to come to his bedside in order that he might impart information concerning certain cave deposits of which he had learned and which he thought it very important that they be examined by a competent scientist. After a sickness of about three weeks, during which paratyphoid fever developed, Doctor Lee died suddenly, on the evening of June 16, 1926, and was buried in Fort Lincoln Cemetery, Washington, D. C. He is survived by his widow, Mrs. Mary Ingham Lee, and his children, Elizabeth L. Lee and Dana Willis Lee.

After describing in his "Stories in Stone" (page 12), the deposition in the former head of the Gulf of California of much of the material derived from the erosion of the Grand Canyon of the Colorado, he seems to have settled back in his chair and allowed his thoughts to wander into the Great Unknown, for he wrote:

> **"But what of the rest? As well ask what has become of a life that is spent! It has passed down the river, it has done its bit toward accomplishing a great task, and has vanished—*somewhere.*"**

We will not attempt to penetrate into his thoughts and beliefs as to what lies beyond the grave. He was for many years a communicant in the Presbyterian Church; at the time of his death he was a member of the Mount Pleasant Congregational Church, in Washington, D. C.

Doctor Lee was for nearly 23 years a fellow of the Geological Society of America. He was for about the same length of time a member of the Geological Society of Washington, and at the time of his death was First Vice-President of that Society. He was also a member of the Society of Economic Geologists, American Association for the Advancement of Science, American Geographical Society, National Geographic Society, and National Parks Association, and to the publications of all of these organizations he was a frequent contributor. He greatly enjoyed his associations with fellow-members of the Geological Survey and partici-

pated in the meetings of several clubs composed of geologists of this and other governmental scientific bureaus, such as the Pick and Hammer Club, Petroleum Club, and Petrologists' Club. As a member of the Washington Academy of Sciences and the Cosmos Club of Washington, he took advantage of the opportunities to extend his acquaintance among explorers and workers in other lines of scientific research than geology. He was also a member of the Society of Sigma Xi and was President of the Washington Chapter of that fraternity in 1925. He had, however, but few intimate friends. The writer counts it a privilege to have been for 20 years one of these few.

Most of the titles in the following list of Doctor Lee's papers are taken from bulletins of the Geological Survey by John M. Nickles, namely, "Geologic literature on North America," 1785-1918, part I, Bibliography Bulletin 746; Bibliography of North American Geology, 1919-1920, Bulletin 731; ditto, 1921-1922, Bulletin 758; ditto, 1923-1924, Bulletin 784 (in press); ditto, 1924-1925 (in preparation).

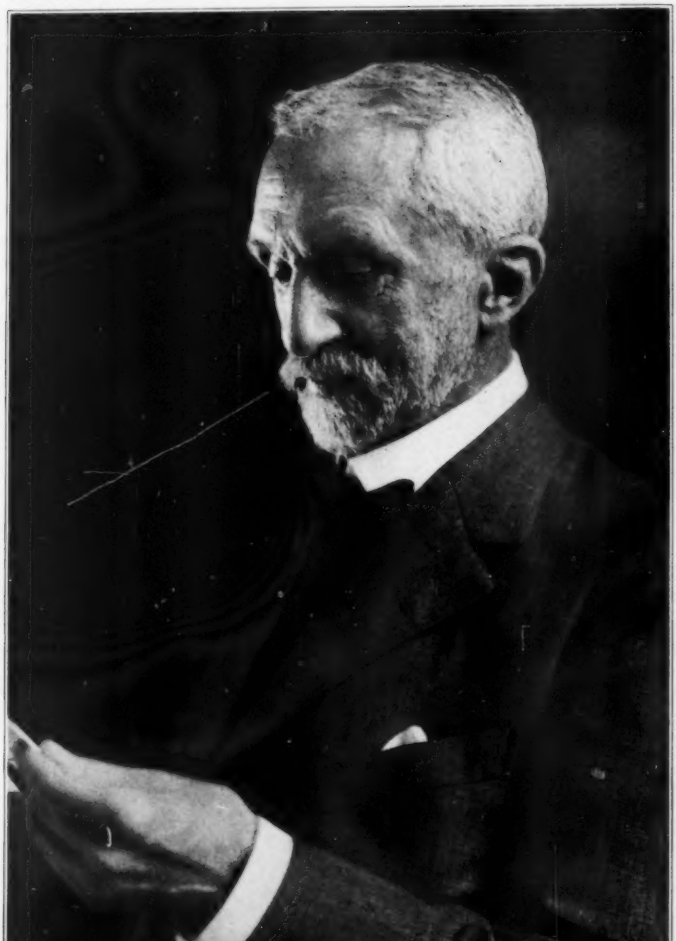
Bibliography

1. Fossil mosasaurid found near Flagler, Colorado. American Naturalist, volume 31, 1897, page 614.
2. The origin of the debris-covered mesas of Boulder, Colorado. Journal of Geology, volume 8, 1900, pages 504-511, map.
3. The glacier of Mount Arapahoe, Colorado. Journal of Geology, volume 8, 1900, pages 647-654.
4. The Morrison formation of southeastern Colorado. Journal of Geology, volume 9, 1901, pages 343-352, map.
5. The Morrison shales of southern Colorado and northern New Mexico. Journal of Geology, volume 10, 1902, pages 36-58, map.
6. Note on the Carboniferous of the Sangre de Cristo Range, Colorado. Journal of Geology, volume 10, 1902, pages 393-396.
7. The areal geology of the Castle Rock region, Colorado. American Geologist, volume 29, 1902, pages 96-110, map.
8. Canyons of southeastern Colorado. Journal of Geography, volume 1, 1902, pages 357-370, map.
9. The canyons of northeastern New Mexico. Journal of Geography, volume 2, 1903, pages 63-82, maps.
10. Age of the Atlantosaurus beds (abstract). Science, new series, volume 17, 1903, pages 292-293: Journal of Geology, volume 11, 1903, page 107; Bulletin of the Geological Society of America, volume 14, 1904, pages 531-532.
11. The underground waters of Gila Valley, Arizona. United States Geological Survey, Water Supply Paper 104, 1904, 71 pages, map.
12. Underground waters of Salt River Valley, Arizona. United States Geological Survey, Water Supply Paper 136, 1905, 196 pages, map.

13. Note on the glacier of Mount Lyell, California. Journal of Geology, volume 13, 1905, pages 358-362.
14. Geology and water resources of Owens Valley, California. United States Geological Survey, Water Supply Paper 181, 196, 28 pages.
15. Geology of the lower Colorado River. Bulletin of the Geological Society of America, volume 17, 1906, pages 275-284.
16. The Engle coal field, New Mexico. United States Geological Survey, Bulletin 285, 1906, page 240.
17. Gypsum beds and water storage in the Pecos Valley of New Mexico (abstract). Science, new series, volume 23, 1906, page 306.
18. The Cove Creek sulphur beds, Utah. United States Geological Survey, Bulletin 315, 1907, pages 485-489.
19. The Iron County coal field, Utah. United States Geological Survey, Bulletin 316, 1907, pages 359-375.
20. Water resources of the Rio Grande Valley in New Mexico and their development. United States Geological Survey, Water Supply Paper 188, 1907, 50 pages, map.
21. Note on the red beds of the Rio Grande region in central New Mexico. Journal of Geology, volume 15, 1907, pages 52-58.
22. Afton craters of southern New Mexico. Bulletin of the Geological Society of America, volume 18, 1907, pages 211-220 (abstract); Science, new series, volume 25, 1907, pages 768-769.
23. The late history of the lower Colorado River (abstract). Science, new series, volume 25, 1907, pages 390-391.
24. Water resources of Beaver Valley, Utah. United States Geological Survey, Water Supply Paper 217, 1908, 57 pages.
25. Geologic reconnaissance of a part of western Arizona. United States Geological Survey, Bulletin 352, 1908, pages 9-80, map.
26. Notes on the Lower Paleozoic rocks of central New Mexico. American Journal of Science (4), volume 26, 1908, pages 180-186.
27. [Fossils from the Red Beds of New Mexico and their age] (abstract). Science, new series, volume 27, 1908, page 247.
28. Local upturning sedimentary rocks at their outcrop (abstract). Science, new series, volume 27, 1908, page 891.
29. The Grand Mesa coal field, Colorado. United States Geological Survey, Bulletin 341, 1909, pages 316-334, map.
30. Unconformity in the so-called Laramie of the Raton coal field, New Mexico. Bulletin of the Geological Society of America, volume 20, 1909, pages 357-368.
31. Stratigraphy of the Manzano group of the Rio Grande Valley, New Mexico. United States Geological Survey, Bulletin 389, 1909, pages 5-40.
32. On an occurrence of coal changed to coke and graphite in the Raton, New Mexico, coal field (abstract). Science, new series, volume 29, 1909, pages 198-199.
33. The correlation of sections lithologically similar (abstract). Science, new series, volume 29, 1909, page 239.
34. Unconformity separating the coal-bearing rocks in the Raton field, New Mexico (abstract). Science, new series, volume 29, 1909, page 624.

35. Criteria for an unconformity in the so-called Laramie of the Raton Mesa coal fields of New Mexico and Colorado (abstract). Science, new series, volume 33, 1911, pages 355-356; Bulletin of the Geological Society of America, volume 22, 1911, page 717.
36. The Tijeras coal field, Barnalillo County, New Mexico. United States Geological Survey, Bulletin 471, 1912, pages 574-578, map.
37. Coal fields of Grand Mesa and the West Elk Mountains, Colorado. United States Geological Survey, Bulletin 510, 1912, 237 pages, maps.
38. Stratigraphy of the coal fields of northern central New Mexico. Bulletin of the Geological Society of America, volume 23, 1912, pages 571-686; abstract in Science, new series, volume 35, 1912, page 311.
39. Extinct volcanoes of northeast New Mexico. American Forestry, volume 18, 1912, pages 357-365.
40. Graphite near Raton, New Mexico. United States Geological Survey, Bulletin 530, 1913, pages 371-374.
41. The Cerrillos coal field, Santa Fe County, New Mexico. United States Geological Survey, Bulletin 531, 1913, pages 285-312, maps.
42. Recent discovery of dinosaurs in the Tertiary. American Journal of Science (4), volume 35, 1913, pages 531-534; abstract in Washington Academy of Science Journal, volume 3, 1913, page 173.
43. Coal fields of Grand Mesa and the West Elk Mountains (abstract). Washington Academy of Science Journal, volume 3, 1913, pages 362-363.
44. Use of physiography in the study of Rocky Mountain stratigraphy (abstract). Washington Academy of Science Journal, volume 4, 1914, pages 8-9.
45. (And others.) Guidebook of the Western United States; Part B, The Overland Route, with a side trip to Yellowstone Park. United States Geological Survey, Bulletin 612, 1915, 244 pages, maps; abstract by F. L. Ransome. Washington Academy of Science Journal, volume 5, 1915, page 580.
46. Relation of the Cretaceous formations to the Rocky Mountains in Colorado and New Mexico. United States Geological Survey Professional Paper 95, 1915, pages 27-58, maps; abstract in Washington Academy of Science Journal, volume 5, 1915, pages 29-30; Bulletin of the Geological Society of America, volume 26, 1915, page 114.
47. Reasons for regarding the Morrison and introductory Cretaceous formation. Bulletin of the Geological Society of America, volume 26, 1915, pages 303-314; abstract in Washington Academy of Science Journal, volume 5, 1915, pages 606-608.
48. The Aztec gold mine, Baldy, New Mexico. United States Geological Survey, Bulletin 620, 1916, pages 325-330.
49. Geology of the Raton Mesa and other regions in Colorado and New Mexico. United States Geological Survey Professional Paper 101, 1917, pages 9-221, map; abstract by R. W. Stone in Washington Academy of Science Journal, volume 8, 1918, pages 451-452.
50. The geologic story of the Rocky Mountain National Park, Colorado. United States National Park Service, 1917, 89 pages, maps.

51. General stratigraphic break between Pennsylvanian and Permian in western America (abstract). Bulletin of the Geological Society of America, volume 28, 1917, pages 169-170.
52. Application of physiographic methods to the correlation of nonmarine formations in the Rocky Mountains (abstract). New York Academy of Science Annual, volume 27, 1917, pages 266-267.
53. Relations of the Morrison and Sundance formations (abstract). Washington Academy of Science Journal, volume 7, 1917, pages 431-432.
54. Early Mesozoic physiography of the southern Rocky Mountains. Smithsonian Miscellaneous Collections 69, 1918, number 4, 44 pages.
55. Type section of the Morrison formation. American Journal of Science, fourth series, volume 49, March, 1920, pages 183-188. Abstract, with discussion by W. H. Twenhofel, Bulletin of the Geological Society of America, volume 31, number 1, March 31, 1920, pages 135-136.
56. Notes on the Manzano group, New Mexico. American Journal of Science, fourth series, volume 49, May, 1920, pages 323-326.
57. Airplanes and geography. Geological Review, volume X, 1920, pages 310-325.
58. Concerning granite in wells in eastern New Mexico. Bulletin of the American Association of Petroleum Geologists, volume 5, number 2, March-April, 1921, pages 163-167 (with discussion by John Rich, W. E. Pratt, R. C. Moore, J. W. Beede, and Arthur Eaton, pages 329-331).
59. The Raton mesas of New Mexico and Colorado. Geological Review, volume 11, number 3, July, 1921, pages 384-397, 13 figures.
60. The face of the earth as seen from the air; a study in the application of airplane photography to geography. American Geological Society, Special Publication number 4, 1922, 110 pages, 82 figures.
61. Description of the Raton, Brilliant, and Koehler quadrangles; United States Geological Survey Geological Atlas of the United States, Raton-Brilliant-Koehler Folio, New Mexico-Colorado (number 214), 1922, 17 pages, 21 figures, 10 maps, section and illustrations sheet.
62. Peneplains of the Front Range and Rocky Mountain National Park, Colorado. United States Geological Survey, Bulletin 730, April 4, 1922, pages 1-17, 3 figures, 8 plates.
63. Continuity of some oil-bearing sands of Colorado and Wyoming. United States Geological Survey, Bulletin 751, April 24, 1923, pages 1-22, 3 figures, 6 plates.
64. Building of the southern Rocky Mountains. Bulletin of the Geological Society of America, volume 34, number 2, June 30, 1923, pages 285-300, 4 figures.
65. Coal resources of the Raton coal field, Colfax County, New Mexico. United States Geological Survey, Bulletin 752, 1924, 254 pages, 18 figures, 22 plates.
66. Geography, geology, and physiography of the Great Salt Lake basin. United States Geological Survey, Water Supply Paper 517, 1924, pages 3-9.
67. A visit to Carlsbad Cavern [Guadalupe Mountains, New Mexico]. National Geographic Magazine, volume 45, number 1, January, 1924, pages 1-40, 42 figures.



John C. Smock

68. Erosion and fill (abstract, with discussion by I. C. White). Bulletin of the Geological Society of America, volume 35, number 1, March 30, 1924, page 99; abstract in Pan-American Geologist, volume 41, number 2, March, 1924, page 149.

69. Erosion by solution and fill [Pecos Valley, New Mexico]. United States Geological Survey, Bulletin 760, April 4, 1925, pages 107-121, 5 figures, 8 plates.

70. New discoveries in Carlsbad Cavern [Guadalupe Mountains, New Mexico]. National Geographic Magazine, volume 45, number 1, September, 1925, pages 301-319, 20 figures.

71. An ice cave in New Mexico. Geographical Review, volume 16, 1926, pages 55-59.

POSTHUMOUS WORKS

72. Stories in stone, 226 pages, 49 plates, 3 figures. D. Van Nostrand Co., New York City, 1926.

73. Correlation of geologic formations between east-central Colorado, central Wyoming, and southern Montana. United States Geological Survey Professional paper 149, 1927, 80 pages, 35 plates, 5 figures.

MEMORIAL OF JOHN CONOVER SMOCK

BY HENRY B. KUMMEL

In the death of John Conover Smock on April 21, 1926, at his home in Hudson, New York, the Society lost one of its charter members, and yet one who was probably unknown except by name to most of the present members; for Dr. Smock, although retaining his interest in geologic studies and in the Society, was of a somewhat retiring disposition and rarely attended its meetings. He missed the older generation of geologists, with whom he had been associated in earlier years, and he was not a man who made new friends readily. Hence I imagine that on the rare occasions when he did attend a meeting for a portion of its sessions he was more or less lonely and glad to get back to his study and the congenial surroundings of his home.

John Conover Smock was the son of Isaac G. and Ellen Conover Smock. He was born September 21, 1842, on his father's farm, one mile south of Holmdel, in Monmouth County, New Jersey, and died in Hudson, New York, on April 21, 1926, aged 83 years and 7 months. He was a descendant, in the seventh generation, of Hendrick Matthyse Smock (or Smack), an emigrant from the Netherlands, who arrived in 1654 and settled in New Utrecht, Long Island. His second son, Johannes Hendrickse Smock, moved to New Jersey in 1712, purchasing a large farm in Monmouth County, which remained in the family for one hundred and sixty years.

The Smock family was a large one. Dr. Smock's grandfather was one of thirteen children and his father one of fifteen, to say nothing of earlier generations. He, however, had no brothers and only one sister, nor did he leave any children.

Both his great-grandfather and his grandfather were Revolutionary officers—one in the Continental army and the other in the New Jersey militia.

His early years were spent on his father's farm, which adjoined the ancestral homestead, purchased in 1712. At that time large quantities of greensand marl were dug for agricultural purposes, and many farms in that neighborhood had their marl pits. Digging, hauling, and spreading marl were the winter occupations of every farmer. It is an interesting question to what extent a natural curiosity regarding the fossil bones and shell so frequently found in these pits determined the later work of this farmer's boy.

Entering Rutgers College in due course, Mr. Smock graduated in the class of 1862. His lifelong interest in the ancient languages, particularly Greek, is an indication that the classics formed no small part of his college course, although geology, chemistry, and metallurgy were his specialties in the succeeding years.

His work after graduation naturally falls into four periods: The first, from 1863 to 1885, when, as associate of Dr. George H. Cook, he was Assistant State Geologist of New Jersey and a member of the teaching force in Rutgers College; the second, from 1885 to 1890, when he was in charge of the New York State Museum, under the direction of Dr. James Hall; the third, when, in 1890, on the death of Dr. Cook, he returned to New Jersey as State Geologist, which position he filled until his resignation, in 1901; the fourth, from 1901 until his death, in 1926.

In 1863 George H. Cook, Professor of Geology in Rutgers College, was carrying on geological studies under the authority of the State Agricultural Society, in which work he was assisted by his former pupil. In 1864 the legislature authorized a State Geological Survey, appointed Cook State Geologist, and Smock was made his assistant—a position which he held for about twenty-one years. During this long period he was most faithful, devoted, and loyal in his service to his chief and to the interests of the Survey.

Although much of the field-work was done by him, one can search almost in vain through the publications of the Survey for these years for papers or reports bearing his name as author. His own work seems to have been largely submerged in that of his chief. The successive annual reports were the reports of the State Geologist, even though the field-

work may have been entirely and the report itself largely the work of the assistant. This is not to say that the elder man deliberately appropriated to himself the work of the younger. It may have been that the relations between the two were, for many years, so close and intimate that there was not much differentiation in their own minds as to whom was the product, or it may have been the result of official custom. In fact, the reports themselves bear no one's name as author. They were officially "Reports of the State Geologist." In a letter of transmittal to the Governor, Dr. Cook usually stated that he was submitting his annual report. Under the heading "Personnel," there was sometimes a brief reference to the work which various members of the staff had been doing, and from these or the opening paragraphs it is sometimes possible for a discriminating reader to differentiate the work of Smock from that of Cook. Whether or not the younger man in the course of time inwardly chafed at this virtual suppression of his individuality is not known. It is a fact, however, that during his régime as State Geologist he was most scrupulous in having every part of his Annual Reports bear the name of the assistant whose work it was.

During this period he spent a portion of two years (1869-1870) in Germany, at the Bergakademic and the University of Berlin. Both before and after these studies abroad, he was a member of the faculty of Rutgers College, tutor in chemistry in 1863-1867, professor of mining and metallurgy in 1867-1885.

As Assistant State Geologist from 1864 to 1885, Smock spent much of his time in mapping the areal geology of the State, and the earlier geological maps were in large part based on his work. In addition to this areal work, the iron ores and the clay deposits were subjects of especial study. In successive annual reports the former are described and progress in their development is recorded. The results of the latter studies were embodied in a comprehensive report, published in 1878, "The clay deposits of Woodbridge, South Amboy, and other places in New Jersey," largely his work.

New Jersey was the first State to complete and publish a topographic map on a scale of 1 inch to a mile. The work was begun about 1879, and to Dr. Smock must be given the credit for suggesting this project and convincing Cook of its necessity before further progress could be made in geologic studies. He had, however, no part in the actual work.

Resigning his position in 1885, he went to Albany as assistant to James Hall, in charge of the New York State Museum. In addition to his duties in the Museum, he found time to prepare and publish reports on the iron-ore districts and the building-stone industry of New York.

On the death of Dr. Cook, in 1889, the managers of the New Jersey Survey naturally turned to Smock as his successor, and in 1890 he returned to New Jersey.

As State Geologist he was more an administrator than an investigator. His energies were turned more to planning new lines of activities and finding men to carry them out than to personal studies. In fact, his own interest was turning in part to other fields than geology. He became much interested in forestry and in the reclamation of marsh lands, particularly in their application to New Jersey, and trips were made to Europe to study these matters first hand in Germany and the Netherlands.

The result of his ten years' work as State Geologist can not be better summarized than by quoting from a minute adopted by the board of managers at the time of his resignation, in 1901:

"After ten years of tactful, efficient, and disinterested conduct of the Geological Survey of New Jersey by Prof. John C. Smock, the board of managers have accepted with great reluctance his resignation of the office of State Geologist. This long and honorable service calls, in their opinion, for a special minute of remembrance and esteem. A coworker with his predecessor, the late Prof. George H. Cook, and imbued with the spirit of his policy, Professor Smock, while maintaining the wise and prudent traditions of the Survey, began at once to enlarge as well as to continue the lines already laid down. He entered into an arrangement with the United States Geological Survey for a division of study—of the rock formations of New Jersey by that office, of the surface formations by his. With the expert collaboration of Prof. R. D. Salisbury, he completed his own very important task, so far as the field-work was concerned, and made a partial cartographic presentation of it; on the other hand, he measurably repaired the deficiency of the National Survey, which was hindered from carrying out its contract except to a limited extent. Professor Smock's accession also marks the beginning of relations with Mr. Lewis Woolman, which have resulted in a fund of information of obvious practical as well as geological value concerning the water-bearing strata of the State and their protraction beyond her borders. Under his administration, too, Mr. C. C. Vermule, for more than twenty years able topographer of the Survey, concluded and published his classic work on the water supply and water power of New Jersey. The State Atlas Professor Smock found completed, but he kept it revised within economic limits, added to it a beautiful relief map, and initiated a new series of sheets, on a scale of two and one-half inches to the mile, which will, like the earlier, and in a still greater degree, anwser the varied needs of industry, tourings for pleasure, and municipal and suburban growth in the State. Professor Smock's solicitude for the forestry interests of New Jersey has not borne fruit than can be seen of all men, but it has paved the way for legislation which will in time redeem the State from reckless and disfiguring waste. The board rejoices that his new leisure will be given ardently to this momentous subject, as well as to geological studies

proper. In concluding this review, the board wishes to place on record its high regard for the personal character of Professor Smock—his integrity, his judgment, his courtesy, his modest self-effacement, his frequent service without compensation, his not infrequent contributions from his private purse to eke out the slender appropriation for the Survey. It counts upon and is assured of his valued counsel hereafter, in an unofficial capacity, and a cordial maintenance of the good feeling subsisting between himself and the managers during the decade of his public usefulness."

The following quotation from a letter to Dr. Smock from the Governor of the State, when he retired, indicates the attitude of the authorities to him and to the Survey:

"I know of no board or department where appropriations have been more cheerfully given, and where the public have been better satisfied with results accomplished, than that of the State Geological Survey. The results attained have been of very great value to the State. This has been due in large measure to the faithful discharge of the duties intrusted to your care, and to the unselfish way in which you have conducted the affairs of your office. As you know, my opportunities for learning what the true feeling is have been exceptional. Surely it must give you some satisfaction to know that the public have appreciated your efforts in behalf of the State, and it gives me pleasure to convey to you this assurance, both in behalf of the other officials, who know what your work has been, and in behalf of myself.

"I regret sincerely, and I know that others join with me in this, that you feel that you ought to resign the position which you have filled so long and so successfully.

"With the assurance of my best wishes and high esteem, I remain,

"Your old pupil and friend,

"(Signed) FOSTER M. VOORHEES."

After his resignation as State Geologist, in 1901, Smock lived first at Catskill and later at Hudson, New York. Possessed of sufficient means to be free from financial worries, relieved of administrative duties and political contacts, which he had never enjoyed, happy in the companionship of his wife, to whom he was devoted, he was at liberty to spend his time in travel, study, and recreation, as wished. His activities were many. He retained his interest in geology and, although he made no personal researches in this line, he contributed financially to the work of others. His interest in arbor culture and forestry was shown by developments on his property at Hudson and by his gift of land to Rutgers College for forestry experimental plantations. He took up again the Greek studies of his college days and shortly before his death had completed the manuscript of an exhaustive lexicon of Greek terms used in science. The patriotism which sent his grandfather and great-grandfather into the armed forces of the Revolutionary War led him to surrender his

beautiful home and grounds at Hudson to the Government as a hospital during the World War, and later to present it as a nurses' home to the Hudson local hospital.

He married Catherine E. Beekman, of Brooklyn, October 15, 1874, and her death in 1922 came as a great shock to him. Her loss cast a cloud of sadness over the later years of his life, for the intimate ties which are the outgrowth of nearly half a century of congenial companionship and affectionship can not be broken without pain and sorrow.

Quiet, unassuming, somewhat diffident and hesitating in manner, Dr. Smock was not a man who made friends readily; but those to whom he revealed himself and who were admitted to the intimacy of his inner life found there an unexpected richness and depth of thought, a wide charity, a great toleration for the beliefs of others, and a deep love for his fellowman. Firm in his own convictions, he was, nevertheless, always receptive to new facts and ready to adopt other interpretations when the facts warranted. He was always kindly in his manner, sparing in criticism, and generous in commendation. Those who were privileged to enjoy his hospitality were impressed with its sincerety and thoughfulness. He was a Christian gentleman in all that these words imply.

In addition to the A. B. degree from Rutgers College in 1862 and the A. M. degree in 1865, Lafayette College conferred upon him the degree of Ph. D. in 1882, and Rutgers the degree of LL. D. in 1902. Besides the Geological Society of America, he was a member of the American Philosophical Society, Fellow of the American Association for the Advancement of Science, the American Institute of Mining and Metallurgical Engineers, the Royal Society of Arts (London), the National Geographical Society, the New Jersey Historical Society, and perhaps of others.

For reasons already given, the list of papers bearing his name is not a long one. In addition to the annual reports of the State Geologist of New Jersey from 1864 to 1885, inclusive, to most of which he made some contribution, and to the reports of the Survey from 1891 to 1901, inclusive, which were prepared and published under his direction, and for each of which he wrote an administrative report, the following papers bear his name:

Bibliography

1874. The magnetic iron ores of New Jersey, their geographical distribution and geological occurrence. Transactions of the American Institute of Mining Engineers, volume 2, pages 314-323.

1878. (With George H. Cook.) Report on the clay deposits of Woodbridge, South Amboy, and other places in New Jersey, together with their

uses for fire-brick pottery, etcetra, 381 pages, maps, plate. Geological Survey of New Jersey, Trenton.

1879. The fire-clays and associated plastic clays, kaolins, feldspars, and fire sands of New Jersey. Transactions of the American Institute of Mining Engineers, volume 6, pages 177-188, 190.

New Jersey (geological formation). Macfarlane's American Geological Railway Guide, pages 89-92.

1882. On the surface limit or thickness of the continental glacier in New Jersey and adjacent States. American Journal of Science, third series, volume 25, pages 339-350. Read to American Associaton for the Advancement of Science. Abstract in Science, volume 1, page 490.

1884. Geologico-geographical distribution of the iron ores of the eastern United States. Transactions of the American Institute of Mining Engineers, volume 12, pages 130-144. Engineering and Mining Journal, volume 37, pages 217-218, 230-232, quarto.

(With George H. Cook.) New Jersey (building stones), Tenth Census of the United States, Report on building stones of the United States and statistics of the quarry industry for 1880, pages 139-146, bound as part of volume X, but with separate pagination. Washington.

(With George H. Cook.) New York (building stones), Tenth Census of the United States, Report on building stones of the United States and statistics of the quarry industry for 1880, pages 129-139, bound as part of volume X, but with separate pagination. Washington.

1885. Evidence of local glaciers in the Catskill Mountain region (abstract). Proceedings of the American Association for the Advancement of Science, volume 33, pages 403-404.

1886. A geological reconnaissance in the crystalline rock region, Dutchess, Putnam, and Westchester counties, New York, New York. Thirty-ninth Report of State Museum of Natural History for 1885, pages 166-185, plate. Albany, 1886.

1889. Iron mines and iron ore districts in the State of New York. New York State Museum Bulletin number 7, 70 pages, map. Albany.

1890. New Jersey. Macfarlane's Geological Railway Guide, second edition, pages 139-140.

Building stones in New York. New York State Museum Bulletin number 10 (volume 2), 396 pages, plate, map. Albany.

1891. Administrative report, pages 9-22; Annual Report of New Jersey. Geological Survey, 1890.

1892. Administrative report, pages 1-29; Artesian wells, pages 217-222; Mineral statistics, iron ore, zinc ore, pages 255-256; Annual Report of New Jersey Geological Survey, 1891.

1893. Administrative report, pages 3-30; Notes on the sea dikes of the Netherlands, pages 315-329; Reclamation of the lowlands of the Netherlands, pages 331-353; Mineral statistics, iron ore, zinc ore, pages 355-356; Annual Report of New Jersey Geological Survey, 1892.

1894. Administrative report, pages 1-29; Minerals of New Jersey, with notes on mineral localities, pages 425-442; Mineral statistics, iron ore, zinc

ore, pages 443-444: Annual Report of New Jersey Geological Survey, 1893.

1896. Administrative report, pages 11-27: Annual Report of New Jersey Geological Survey, 1895.

1897. Administrative report, pages 11-34; Mineral statistics, iron ore, zinc ore, pages 367-369; Annual Report of New Jersey Geological Survey, 1896.

1898. Administrative report, pages 13-36; Mineral statistics, iron ore, zinc ore, pages 351-353; Statistics of clays, bricks, terra-cotta, and other clay products, pages 355-357; Annual Report of New Jersey Geological Survey, 1897.

1899. Administrative report, pages 13-32; Mineral statistics, iron ore, zinc ore, pages 239-240; Annual Report of New Jersey Geological Survey, 1898.

1900. Administrative report, pages 11-35; Mineral statistics, iron ore, zinc ore, pages 177-179; Preface to forestry report, 1899, pages 5-8; Annual Report of New Jersey Geological Survey, 1899.

1901. Administrative report, pages 11-40; Mineral statistics, iron ore, zinc ore, pages 215-217: Annual Report of New Jersey Geological Survey, 1900.

1922. Genealogical notes on the Smock family in the United States. Frederick S. Hills, publisher, Albany, New York.

MEMORIAL OF WILLIAM LAWRENCE UGLOW [1]

BY M. B. BAKER

"The days of our years are threescore years and ten; and if by reason of strength they be fourscore years, yet is their strength labor and sorrow; for it is soon cut off, and we fly away." It is difficult at any time for close friends or relatives to reconcile themselves to the passing of one who has fulfilled the natural expectation of years and has rounded out a life of usefulness. By others death is expected and does not cause a great gap, nor excessive regret; but when the grim reaper selects a plant in its flowering stage, a young, vigorous life, in the very prime of its usefulness and promise of fruition, it is difficult for any one to reconcile himself to "an order apparently so irrational."

The death of Uglow removed a man in the prime of life—only forty-two years old—who had already done much useful scientific work, but who was undoubtedly destined to make many and valuable contributions to the study of geology. His place in the field of science will no doubt be filled by others of equal academic ability; but to find another so unselfish, so impersonal, so conscientious, so sympathetic, so friendly, so fair, and so free from pettiness; another with such a practical turn in

[1] Manuscript received by the Secretary of the Society December 18, 1926.

Yours Sincerely,
W. L. Mc Gee

the field, and so ready to help the prospector and miner with his difficulties, will be most difficult.

"Uglow has gone, but he is not lost to us; such men as he mean more good to the world than can ever be lost again. Can uprightness be rounded off to perfection. Can the search after truth be concluded? These spell the purpose of life, and an inexorable fate has glorified that purpose with immortality, and has left with us a finished picture of an inexhaustible ideal, that we and the world at large may follow his example."

William Lawrence Uglow was born in Ottawa, the capital of the Dominion of Canada, on April 29, 1884. His forebears for generations were British. On his father's side the Uglows were Welsh and were among the earliest settlers of Huron County. His grandfather settled in Goderich, Ontario, on the shores of Lake Huron, and his father, Richard Uglow, was born in Goderich in 1854, but, being left an orphan at quite an early age, went to Ottawa to live with relatives. There he was engaged in the book business for about fifteen years. In 1893 he moved to Kingston, Ontario, and continued the book and stationery retail business till his death, in 1920, and was one of the most highly esteemed citizens of this city.

On his mother's side the Lawrences were Scotch and had for generations lived in Aberdeenshire, Scotland. Some of this family also migrated to Canada and Uglow's mother was born in Ottawa. She, with two daughters, still lives in Kingston, and if words could be spoken that would comfort them in their sad loss we do most sincerely offer them. This sympathy is all the more feelingly tendered, since this is the second tragic blow the family has suffered. In 1915 Uglow's only brother, Henry Wright, just two years his junior, gave up his position with the Merchants Bank of Canada to offer his services for king and country. He went overseas with the 8th brigade, Canadian Mounted Rifles, and in June, 1916, after the battle of Sanctuary Wood, was first reported missing, and a few days later he was reported killed in action.

At the age of nine, "Laurie" Uglow entered the public schools of Kingston on transfer from Ottawa. He proceeded through them to the Collegiate Institute and in 1902 entered Queen's University, where he was graduated M. A. in 1906 with honors in English. He seemed, however, to have an inclination for the scientific side of truth, and spent the following year and a half on a Grand Trunk Pacific survey party in northern Ontario. He returned to Queen's University in the fall of 1907 to take a course in geology and mineralogy.

In 1911 he was graduated B. Sc. with honors in these subjects, and at once proceeded with postgraduate work, taking his master's degree the

following year, 1912. From Queen's University he went to the University of Wisconsin in the fall of 1912, and continued his studies in geology and mineralogy, and received his doctor's degree from that institute in 1915. Three years later he joined the geological staff of the University of British Columbia at Vancouver, where he continued to serve with striking success until his death, in August, 1926.

At the December meeting of the Geological Society of America, held at Ann Arbor, Michigan, in 1922, he was declared elected to fellowship in the Society. In 1925 he was honored by being made a fellow of the Royal Society of Canada, and in December of the same year was elected a member of the Society of Economic Geologists.

Thorough as was his academic training, his practical field experience was, if anything, more intensive and broad. He began as a student assistant in 1906 on a Grand Trunk Pacific Railway survey party and continued for two years. In 1909 he acted as an assistant to G. A. Young in a geological survey of the Bathurst District of New Brunswick, Canada. In 1910 he was engaged by the Ontario Bureau of Mines in an investigation and report on the Alexo Nickel Mines of northern Ontario, and this was his first independent publication. The detail and laboratory work formed the subject of his research for his bachelor's degree in science at Queen's University in 1911.

In 1912 Uglow was engaged as an assistant on a Canadian Geological Survey party mapping the Duncan area on Vancouver Island, British Columbia, and during the absence of his chief, C. H. Clapp, he took charge of the party. During this same summer Mr. J. D. Trueman, who was conducting a geological survey of the Rainy River district, in Ontario, for the Canadian Geological Survey, was drowned in the Seine River near Steeprock Lake, through the upsetting of a canoe, and Uglow was assigned the task of completing the work and preparing the information necessary for the guidebook for the excursion to this area of the International Geological Congress, which met that year in Canada.

In 1913 and 1914 Uglow was engaged with the Wisconsin Tax Commission in the work of mine valuation, and in 1915 was engaged by the Vinegar Hill Zinc Company of Wisconsin as field geologist in the examination of lead and zinc deposits In 1916 he went to South America as geologist to the Cerro de Pasco Copper Mining Company, but returned to Canada in the fall of 1917 and offered himself for overseas war service, following the example of his only brother, who had given his life at Sanctuary Wood. He was not accepted, however, and immediately then offered his services to the Canadian Munition Resources Commis-

sion and was assigned the task of looking up supplies of manganese and platinum.

At the conclusion of the war he was appointed to the geological staff of the University of British Columbia and resumed field-work for the Canadian Geological Survey. In 1921 he mapped a considerable area in the North Thompson River valley of British Columbia, and in the following year collaborated with W. A. Johnston in a study of part of the Cariboo district in the vicinity of Barkerville, British Columbia, mapping the bedrocks of several hundred square miles. Memoir Number 149, entitled "Placer and vein gold deposits of Barkerville, Cariboo district, British Columbia, is now in press and will be issued early in 1927. During part of 1923 and 1924 Uglow was engaged to complete a study of the iron ore deposits of British Columbia and the Yukon, upon which G. A. Young had been engaged during 1922 and 1923. The results of this investigation are to appear during this month in "Economic Geology" series, Report Number 3, Canadian Geological Survey, under the title of "The iron ores of Canada, volume 1, British Columbia and Yukon," and under the joint authorship of G. A. Young and W. L. Uglow.

The year 1925 was a momentous one in the career of Uglow. At the close of his teaching session at Vancouver he began a systematic study of the manganese deposits of Canada, and by the end of the field season had examined all the known occurrences in Nova Scotia and New Brunswick. His tragic death occurred before he had begun his report on this work, but he had examined some other mineral deposits in New Brunswick as well, and his report on them will appear in the Summary Report for the Canadian Geological Survey for 1925, part C, and will be issued early in 1927. Instead of returning in the fall to his classes at the University of British Columbia, he was sent to China to complete a geological survey of the Hongkong District for the British Government. This work had been undertaken by R. W. Brock some four years previously and was to be done by the geological staff of the University of British Columbia. Dean Brock himself, M. Y. Williams, and S. J. Schofield had each spent a season on this work, and Uglow was taking his turn and was to complete the field-work. This was finished in April, 1926, and Uglow was on his way home to Canada when he met his death.

The above sketch of his field experiences will indicate how thorough was the training of this young man and what an increasingly valuable service he would have rendered the geological and mining interest of this country.

The Vancouver Daily Province, commenting editorially on his death, contained the following paragraph:

"Dr. Uglow was a practical as well as a theoretical scientist. He knew the hills as well as he did his textbooks and specimen cases, and, knowing the hills, he had a lively appreciation of the difficulties of the men who strive to make a living there. He had every sympathy for the prospector and realized the importance of the prospector to the mining industry. He saw that methods of prospecting were changing and spared no pains to give the men who follow this rather uncertain calling a better scientific training. To this end he lectured and demonstrated night after night during several winters to classes organized by the Mining Institute. The prospectors of British Columbia will go far before they find a better or a more able friend than the one they have lost."

Uglow was married in 1917 to Miss Mattie Robertson, daughter of the late William Robertson and Mrs. Robertson, of Peterboro, Ontario. Mrs. Uglow, with their only child, Elizabeth, aged six years, had gone to Honolulu to meet her husband and spend what was to have been a happy holiday. She arrived on May 12, just two days after he had arrived from Hongkong. Two days later, while surf bathing at Waikiki Beach, in the presence of a thousand other holiday folk, he attempted one more dive into a roller. He apparently misjudged the distance and dived short, striking the hard sand in very shallow water, while the roller broke over him, and he was stunned. He was picked up by companions, and medical examination showed that his spine had been so injured, just about his shoulders, that recovery was impossible. His head was not injured and he was mentally as bright as ever, but after two months in hospital in Honolulu, with the best of specialists' care, it was decided to move him to his home in Vancouver. He arrived without any untoward experiences, but died on August 3 at his home, and was buried in Ocean View cemetery, Vancouver, British Columbia.

Uglow's publications have been quite varied and, for so young a man, quite voluminous, as the following list will show:

Bibliography

1911. The Alexo nickel deposit. Ontario Bureau of Mines, Annual Report, volume 20, part 2, pages 34-39, 6 figures.

The Alexo mine: A new nickel occurrence in northern Ontario. Canadian Mining Institute, Journal, volume 14, pages 657-677, 5 plates, 4 figures.

1913. Discussion of paper by E. S. Moore on "Hydrothermal alteration of granite and the source of vein quartz at the Saint Anthony Mine." Economic Geologist, volume 8, pages 797-800.

Port Arthur to Winnipeg via Canadian Northern Railway. Geological Survey, Department of Mines, Ottawa, International Geological Congress Guidebook Number 8, pages 37-69.

A review of the existing hypotheses on the origin of the secondary silicate zones at the contacts of intrusives with limestones. Economic Geologist, volume 8, pages 19-50, 215-234, 2 figures.

1914. "Secondary silicate zones": A reply to criticisms by J. F. Kemp and C. A. Stewart. Economic Geologist, volume 9, pages 175-183.

1915. A study of method of mine valuation and assessment, with special reference to the zinc mines of southwestern Wisconsin. Wisconsin Geological and Natural History Survey, Bulletin number 41, Economic Series, number 18, pages 1-72, 12 plates.

1916. Lead and zinc deposits in Ontario and in eastern Canada. Ontario Bureau of Mines, Annual Report, volume 25, part 2, page 56, 3 figures.

Origin of certain ore deposits. Economic Geologist, volume 11, number 1, pages 87-92.

Ore genesis and contact metamorphism at the Long Lake zinc mine, Ontario. Economic Geologist, volume 11, pages 231-245, 1 plate, 1 figure.

1917. Gneissic galena ore from the Slocan District, British Columbia. Economic Geologist, volume 12, pages 643-662, 4 plates, 5 figures.

1919. Geology of platinum deposits. Engineering and Mining Journal, volume 108, pages 352-355, 390-392.

1920. Bog manganese deposits, Upper North Branch, Canaan River, Westmoreland County, New Brunswick. Canada Munition Resources Commission, Final Report, pages 65-79, 2 plates, 1 figure.

Bog manganese deposits, Dawson Settlement, Albert County, New Brunswick.

Canada Munition Resources Commission, Final Report, pages 79-88, 4 plates.

Manganese mines, Colchester County, Nova Scotia. Canada Munition Resources Commission, Final Report, pages 88-89.

An investigation of an alleged occurrence of platinum on Peace River, British Columbia. Canada Munition Resources Commission, Final Report, pages 156-160.

Douglas gold-platinum gravels, North Saskatchewan River, Alberta. Canada Munition Resources Commission, Final Report, pages 185-194, 6 plates.

Possibilities of platinum in western Canada. Mining and Engineering Record, volume 24, numbers 23-24, pages 410-413.

1921. Possibilities for platinum in western Canada. Transactions of Canadian Mining Institute, volume 23, pages 374-389.

An unusual copper-lead deposit. Legato Creek, British Columbia. Mining and Science Press, volume 123, pages 197-199, 4 figures.

1922. Quartz veins of Barkerville, Cariboo district, British Columbia. Canadian Institute of Mining and Metallurgy, Bulletin number 127, pages 1165-1175.

Geology of the North Thompson Valley map area, British Columbia. Canada, Department of Mines, Geological Survey, Summary Report, 1921, part A, pages 72-106, 2 plates, 12 figures, 1 map.

The Eocene coal basin at Chu Chua, British Columbia. Canadian Institute of Mining and Metallurgy, Bulletin number 124, pages 896-902, 906-907.

A so-called bornite-chalcopyrite intergrowth. American Mineralogist, volume 7, pages 1-4, 4 figures.

1923. Cretaceous age and early Eocene uplift of a peneplain in southern British Columbia. Bulletin of the Geological Society of America, volume 34, pages 561-572, 4 figures.

Bedrocks and quartz veins of Barkerville map area, Cariboo District, British Columbia. Canada, Department of Mines, Geological Survey, Summary Report, 1922, part A, pages 82-87.

Undiscovered mines of British Columbia. Canadian Institute of Mining and Metallurgy, Bulletin number 138, pages 595-613. This paper was awarded the Leonard gold medal by the Institute for its excellence.

Discussion of a paper by George Hanson entitled "The Dolly Varden Mine." Canadian Institute of Mining and Metallurgy and Transactions of Mining Society of Nova Scotia, 1922, volume 25, page 224.

The Eocene coal basin at Chu Chua, British Columbia. Transactions of Canadian Institute of Mining and Metallurgy and of Mining Society of Nova Scotia, volume 25, 1922, pages 370-376.

Origin of the placer gold of the Barkerville area, Cariboo district, British Columbia, Canada. Economic Geology, volume 18, pages 541-561, 3 figures. (With W. A. Johnston.)

British Columbia as a mining province. Mining Magazine, volume 29, pages 73-81, 1 figure. (With H. C. Nichols.)

1924. Ore problems and the microscope. Canadian Institute of Mining and Metallurgy, Bulletin number 147, pages 495-504.

The windpass gold mine, Chu Chua, British Columbia. Canadian Mining Journal, volume 45, pages 47-49, 4 figures.

1925. "The geological aspects of the Po Hing Fong collapse." Reported in a personal communication from the governor of the colony of Hongkong as "a very valuable piece of work." Details as to where published not yet obtainable.

1926. Placer and vein gold deposits of Barkerville, Cariboo District, British Columbia. Canadian Geological Survey Memoir number 149. (With W. A. Johnston.)

The iron ores of Canada, volume 1, British Columbia and Yukon. Canadian Geological Survey, Economic Geology series, Report number 3. (With G. A. Young.)

SESSION FOR THE PRESENTATION OF SCIENTIFIC PAPERS

TITLES AND ABSTRACTS OF PAPERS

WHAT CAUSED THE SPOKANE FLOOD?

BY J HARLEN BRETZ

(*Abstract*)

New data will be presented on the distribution and character of channeled scabland and associated gravel deposits on the Columbia Plateau. They indicate that the Spokane flood was an even greater affair than previously thought. Studies in Washington and British Columbia north of the scabland strongly suggest that basaltic flows which were extruded beneath the Cordilleran ice sheet produced the great flood. The field has not yet been sufficiently studied to justify a definite affirmative. The paper is a report of progress in following up a promising clue.

Brief remarks were made by Dr. F. W. Sardeson.

SALIENT POINTS IN TERTIARY EPEIROGENY

BY FRANK B. TAYLOR

(*Abstract*)

The following points are discussed: 1. The Tertiary mountain belt is distinctly divisible into characteristic sections corresponding to the several continents, showing that the belt is *continental*, not oceanic, in its origin.

2. The distribution of continental movements—northern continents moving in southerly directions and southerly continents moving in northerly directions—must necessarily be in accord with the distribution of the crust-moving force, which is obviously related to latitude and to hemispheres.

3. No contractional or other internal force can be supposed to conform to the observed distribution of crustal movements. Hence, the cause of movement is an *external force*. Tidal and rotational forces are the only ones known to conform to this distribution of crustal movements.

The potent thing in axial rotation, as affecting the equilibrium of the earth's crust, is centrifugal force. If tidal force in its direct action is too weak, as claimed by mathematicians, then we seem driven to assume tentatively that it acts in some *indirect* way. Barring electrical and magnetic forces, which have not even been suggested thus far, no other external force is available except the centrifugal force of rotation. The older explanations of the cause of rotation depended on some form of contraction of the mass of the earth (Laplace, Helmholtz, Kelvin); but with these doctrines abandoned as unsound, under present knowledge, and with the validity of the planetesimal hypothesis still in doubt, axial rotation is left without any explanation whatever. Mathematicians show that the oceanic tide acts like a brake on the rotating earth; but is it certain that the body-tide in the rigid-elastic globe acts in the same way? Before this question is decided, note should be taken of the following remarkable coincidences and their bearing on the cause of crustal movements:

(1) The tidal force and the centrifugal force of rotation conform to the same plan or law of distribution on the earth, and they affect the earth's figure in the same way.

(2) The distribution of the Tertiary continental crust movements also conforms to the same law, the crust sliding from high latitudes toward lower latitudes in both hemispheres.

(3) The making of the Tertiary mountain belt began in the late Cretaceous, closely following the great transgression of the Cretaceous ocean.

The distribution of this transgression, confined almost entirely to latitudes lower than 60 degrees, suggests that it was caused by a small, but relatively sudden, increase in the oblateness of the ocean's figure. In his later writings Suess suggested this kind of change. This and the later relatively sudden beginning of the Tertiary diastrophism over the whole earth demand a cause which can not be supplied by any of the older hypotheses.

If we picture the power of the tidal force as permanently increased in the late Cretaceous to two and one-fifth times the value of the solar tidal force, and if it has ever since been slowly increasing the speed of rotation, the Tertiary crustal movements and mountain-making are fully explained, both in time and in the plan of their distribution. The capture directly out of space and the permanent retention by the earth of a great satellite like the moon would supply all of the elements needed to explain the great crustal movements which began in the late Cretaceous and continued in slowly diminishing effects down to the present time. The solar tidal force was acting through all of the known geological periods before the Cretaceous and was not increased at that time. It is, therefore, of secondary importance in the Tertiary-to-present diastrophism.

4. Since Europe was affected by the same crust-moving forces as affected Asia and North America, there is no good reason for making Europe an exception among the other continents with regard to the direction of its sliding. Europe must have slid *southward*. Contrary conclusions reached by geologists practicing the cross-section method of study must ultimately give way to the broader method of Suess.

5. Greater Asia has about five times the area of Greater Europe. The tremendous mass of Asia sliding southward overwhelmed and closed up the eastern part of Tethys, but the much smaller mass of Europe, moving a shorter distance, failed to close the western part, thus leaving the present Mediterranean basins open.

6. Drawn on a true vertical as well as horizontal scale, the Mediterranean basins reveal the possibility that thick competent strata may pass in a gentle syncline under these basins to Africa. Apparently, a southward thrust-force propagated through them has made the Atlas ranges. Upbulging of the strata on the north side of the basins might easily result, producing Heim's fan structure and backward-thrust recumbent folds.

7. The Antillean arcs appear to be mainly South American. The Galapagos Islands stand on a submerged bank which extends through Costa Rica and Nicaragua to Jamaica and Haiti.

8. The tension area of the North Polar region, with its great rifts and disjunctive basins for each continent and different in each case, is the

physical complement of the compression belt, comprising the Tertiary mountain ranges in the south. They are respectively the proximal and distal products of one action—a crust-sheet sliding toward the south.

9. The Aleutian arc and associated features are strictly homologous with those of the American coast between the mountain angle in Alaska and Puget Sound. The great difference of form is partly one of scale, but mainly one of intensity or maturity of development.

10. Because the two Americas show a strong westward deflection, Wegener erroneously inferred the same movement for Asia and Australia; but in truth the eastern half of Asia shows a marked eastward deflection, and so does Australia. The westward deflection of the Americas was probably due to preexisting weaknesses arising from an unsymmetrical feature of the globe. Wegener's explanation of festoon arcs, foredeeps, and arcseas by posterior splitting off and lagging behind the westward drifting continents of Asia and Australia is shown to be an error.

WHITTLING DOWN THE BATHOLITHS

BY ROLLIN T. CHAMBERLIN

(*Abstract*)

Although T. C. Chamberlin, Iddings, Broegger, and perhaps others have long held that the characteristic shapes of large plutonic masses are flattish or lenticular, with the horizontal dimensions prevailingly greater than the vertical, graduate students quizzed in the last dozen years have been found almost invariably to picture batholiths as enormous masses which either maintain their surface diameters to great depths or else widen into still greater masses with increasing depth. With a solid earth, intrusions of the vast dimensions thus postulated encounter serious difficulties.

Field studies, particularly in the Colorado Rockies, reveal the fact that certain so-called batholiths are horizontally extensive, but of more limited extent vertically, and are thus pancake-shaped, mushroom-shaped, or possibly tack-shaped, in which the head of the tack represents the visible portion of the intrusion and the shaft of the tack the conduit from below. Intrusions of these shapes can take place much more readily than the great masses commonly pictured, and should be much more abundant. One should expect that many of the so-called batholiths in regions of low relief, if their lower portions were only exposed to view, as in the case of some regions of high relief, would exhibit a similar pancake shape or tack shape. The recent work of Cloos and his colleagues seems to bear this out.

The so-called batholiths of the Haliburton-Bancroft area illustrate how, in another way, the volume of intrusive rock proves to be much less than originally thought, as brought out by Foye.

SYMPOSIUM ON PRECAMBRIAN GEOLOGY

At this point in the program the papers constituting the symposium on Precambrian geology were introduced, and the order of presentation somewhat revised by the Chairman of the Symposium Committee. Doctor

Sederholm's paper, in his absence, was transferred to the afternoon session, to give more time to the papers whose authors were in attendance.

PRECAMBRIAN ROCKS OF THE UNION OF SOUTH AFRICA

BY ARTHUR W. ROGERS

(*Abstract*)

As the oldest fauna known in South Africa is Devonian, the upper limit of the Precambrian is chosen arbitrarily. It is assumed that the Waterberg rocks, on which the Karoo beds rest unconformably, are the latest Precambrian present.

The oldest South African rocks are known as the Swaziland system. This includes most sedimentary types, together with iron formations, and volcanics intruded by granitic rocks and highly metamorphosed. They are distributed so as to form a broad arc on the north side of the great Karoo Basin.

In the vicinity of southern Transvaal are found the Witwatersrand and Ventersdorp systems resting with marked unconformity on the Swaziland rocks. Although the Ventersdorp overlaps the Witwatersrand unconformably, these systems are in general closely related. The deltaic origin of the Witwatersrand and the great mass of lavas in the Ventersdorp suggest that this period was one of diastrophism marked at its close by increasing volcanic activity. A glacial origin has been claimed for some 25 feet of boulder- and pebble-bearing mudstone in these rocks.

The Transvaal system and the correlated Nama beds are of great extent and overlie the Ventersdorp system unconformably. The lowest beds are arenaceous, the next form a great dolomite formation, and the topmost ones are mainly argillaceous and quartzitic and include an extensive tillite.

The Transvaal period was brought to an end in the north by outpourings of felsitic lavas, which initiated the long sequence of igneous activity giving rise to the Bushveld igneous complex. In the southwest, granite intrusions, such as the granite invading the Malmesburg beds (Transvaal system) of the Cape, are referred to this period.

The Waterberg Series, resting unconformably on the Transvaal and older rocks in the north, closes the Precambrian successions. This series is mainly sandy, and resemblances have been noted between it and the Torridonian of Scotland.

This paper, in the absence of the author, was read in condensed form by Dr. C. W. Swanson.

LAKE SUPERIOR PRECAMBRIAN

BY C. K. LEITH

(*Abstract*)

Recent studies of the origin of the iron formations of the Lake Superior region, including those of Collins, Gruner, Hawley, and others yet unpublished, tend, on the whole, to show that the iron formations are inorganic chemical

precipitates, that organic agencies have played a small part, that volcanic sources have made notable contributions, and that normal processes of weathering have likewise been effective. All of these factors have been previously recognized, but can now be more specifically identified. The studies of secondary concentration of the iron ores themselves have not changed earlier concepts of the processes.

Evidence has accumulated to indicate that the Gogebic and Marquette iron-bearing series may be of the same age rather than respectively Upper and Middle Huronian. If this correlation should be proved, new light will be thrown on the entire question of correlation of the Lake Superior Precambrian. The fact is stressed that there are three known periods of plutonic intrusion and orogenic disturbance, followed in each case by erosion, to be used as a basis for correlation. One of the causes of difference in correlation of the United States and Canadian geologists is that the Canadian geologists have usually emphasized only two such periods, namely, the Algoman and Killarnean (Keweenawan?), and have somewhat minimized the earlier one, the Archean. Some of the consequences of this difference in emphasis are sketched. The Killarnean disturbance affected all the region south of Lake Superior and probably included the formation of the Lake Superior syncline. The Algoman is recognized only north of the Lake. Evidence is not yet available to localize the Archean disturbance.

BELT SEDIMENTATION AND CORRELATION

BY EDWARD SAMPSON

(*Abstract*)

That portion of the Belt series which is found in the Pend Oreille district of northern Idaho presents its thickest known section. A careful comparison of the sedimentary record with that of southern British Columbia and Montana, as far east as the type section in the Belt Mountains, leads to a correlation which differs from those of former workers.

The proposed correlation shows a similar succession in each district, and for the whole region shows that there are systematic variations in the sediments which are in accord with a theory as to their source and the conditions under which they were deposited. Previous correlations have failed to satisfy this test.

Brief remarks were made by Messrs. Eliot Blackwelder and A. C. Lane.

SUMMARY OF THE PRECAMBRIAN GEOLOGY OF PENNSYLVANIA AND MARYLAND

BY A. I. JONAS AND E. B. KNOPF

(*Abstract*)

The Precambrian rocks of Pennsylvania, Maryland, and Virginia occur in northeastward-trending belts, of which there are three in Pennsylvania: (1) The southeastern Piedmont; (2) The Honeybrook upland and Hellam and Pigeon Hills areas; and (3) The Reading-Durham Hills and South Mountain

areas. The southeastern Piedmont belt crosses Maryland and Virginia and numbers 2 and 3 belts of Pennsylvania from Maryland southward are united in the Catoctin-Blue Ridge anticlinorium.

The southeastern Piedmont belt of Pennsylvania and Maryland contains strongly metamorphosed Precambrian gneisses and schists, mainly of sedimentary origin. The oldest formation, the Baltimore gneiss, is a biotite gneiss, with some hornblendic bands, intruded by a granite, the Hartley augen-gneiss. The Glenarm Series, which unconformably overlies the Baltimore gneiss, is a succession of metamorphosed sediments perhaps 10,000 feet in thickness. The base of this series is the Setters formation, consisting of mica schists and quartzite, overlain by Cockeysville marble which in places overlaps on the Baltimore gneiss.

The marble is overlain by the Wissahickon formation, a thick succession of schist and quartzite beds, developed in two metamorphic facies, an oligoclase-mica schist and an albite-chlorite schist, exposed on either side of the Peach Bottom syncline. This syncline contains the Peters Creek chlorite schist and quartzite which overlies the Wissahickon formation. On both sides of the Pennsylvania-Maryland line Cardiff conglomerate and Peach Bottom slate, provisionally considered to be Precambrian because of lack of fossils, overlie the Peters Creek formation. Igneous rocks ranging from granite to gabbro have intruded the Baltimore gneiss and Glenarm series. Metamorphosed effusive rocks of late Glenarm age occur in the western part of the belt in southern Pennsylvania and become widespread southwestward in Maryland, where they are interbedded with Cockeysville marble.

A summary of this paper, in the absence of the authors, was presented by Prof. E. B. Mathews.

SUMMARY OF THE PRECAMBRIAN GEOLOGY OF VIRGINIA TO THE JAMES RIVER

BY A. I. JONAS

(*Abstract*)

The gneisses, schists, and intruded igneous rocks of the southeastern belt of Pennsylvania and Maryland extend southwest across Virginia. North of the James River the greater part of the sediments lie west of the Peach Bottom syncline, which crosses the James River near Bremo Bluff. East of this syncline granite rocks cover a wide area.

The Precambrian rocks of the Honeybrook upland are highly metamorphosed schists and gneisses with interbedded quartzite and marble, locally containing considerable graphite. They are probably of pre-Glenarm age and tentatively correlated with the Baltimore gneiss. They are intruded by granite gabbro and anorthosite. The rocks of the Reading-Durham Hills lying in the third belt are lithologically similar to those of the Honeybrook upland and are directly continuous with the Precambrian rocks of the Highlands of New Jersey and New York.

The Precambrian core of the Hellam and Pigeon Hills, which forms the southwestern part of the middle belt of Pennsylvania, consists of altered

rhyolite and basalt flows like those exposed in the Precambrian areas of South Mountain south of Carlisle.

These volcanics extend southward across Maryland and Virginia in the Catoctin Blue Ridge anticlinorium and form the greater part of the Precambrian rocks of this belt north of the Potomac River. In Virginia and southern Maryland they are intruded by quartz monzonite and more basic rocks. At the Potomac River and south of it remnants of the Precambrian basement are exposed in the anticlinorium. These sediments include the Cockeysville marble in Loudoun County in the area between Catoctin Mountain and Short Hill and mica schists farther southwestward.

Read by title in the absence of the author.

At this point, 12.35 p. m., the session adjourned for luncheon.

Session of Monday Afternoon

The afternoon session was opened at 2 o'clock, in the Auditorium, with President Lawson in the chair.

TITLES AND ABSTRACTS OF PAPERS

PRECAMBRIAN GEOLOGY OF FENNOSCANDIA, WITH SPECIAL REFERENCE TO FINLAND

BY J. J. SEDERHOLM

(*Abstract*)

The classification of the Precambrian of Fennoscandia proposed by the writer is mainly based on the relations of the sedimentary rocks to such granites as indicate important periods of diastrophism. Four different great groups of granites are distinguished.

The oldest comprises mainly gneissose granites which have been regarded by several authors as "crustal." However, they are younger than the oldest supercrustal complex, the so-called *leptite formation* (*Svionian*).

It is now proved that sedimentary and volcanic rocks (*Bothnian*, possibly also *Ladogian*) exist whose age is intermediate between that of the oldest gneissose granites and the granites of the second group, and which lie unconformably upon the Svionian.

There are also folded sedimentary rocks (*Kalevian*) which are younger than the granites of the second group, but penetrated by those of the third. Both the Kalevian and the Jatulian possess a Huronian type. Their mutual relations are not yet quite clear. The Jatulian has been thought to be younger than the post-Kalevian granites, but it seems possible that the Jatulian rocks have escaped granitization and are less metamorphic than the rocks of Kalevian type only because they have been preserved while lying in an area of greater resistance.

The *Jotnian* sandstones, which are younger both than the granites of the

third and those of the fourth group (the Rapakivi granites), closely resemble the Keweenawan rocks of North America.

As to the older sedimentary rocks, there is some analogy between the Bothnian rocks, which often include great masses of metabasalts (among them pillow lavas), and the Keewatin of North America. If that correlation should prove correct, the Svionian would be older than any formation in North America hitherto described.

The rocks of Huronian type in Fennoscandia have been folded and metamorphosed long before the dawn of the Jotnian. The latter mentioned have at one place undergone a feeble folding, but there is no sign of a stronger diastrophism in Jotnian or post-Jotnian time.

Presented in abstract exfemporaneously by Dr. R. C. Emmons in the absence of the author.

STRATIGRAPHY OF THE NORTHERN SUBPROVINCE OF THE LAKE SUPERIOR REGION

BY T. L. TANTON[1]

(*Abstract*)

Using only formational terms, a statement is made regarding the results of mapping, by the Geological Survey of Canada, westerly from the Timiskaming subprovince. The author's opinions are given regarding the succession and classification of the rocks in Rainy River district based on intensive field studies in recent years. The Kaministikwia group of Upper Copper-bearing series of Logan has been found to be divisible into three series which are presumably intimately related in time.

The stratigraphic succession for the subprovince as a whole is:

Kaministikwia group:	(Granite intrusive)
	Osler series
	Sibley series
	Animikie series
	Great unconformity
Basement Complex:	Batholithic intrusives
	Series based by a granite-pebble-bearing conglomerate
	Unconformity
	Batholithic intrusive
	(not positively identified in the field)
	Volcanic complex
	Sedimentary, mica schist assemblage

The new terms Kaministikwia, Osler and Sibley are advocated by the author, but have not yet been adopted by the Geological Survey.

The author finds no field evidence for correlating any of the rocks of the subprovince with the Cobalt or Bruce series of the Timiskaming region.

[1] Introduced by M. E. Wilson.

The brilliantly reflecting feldspars of the crystalline rocks in the smoothed floor on which the Animikie sediments were laid and the general lack of residual weathering products are interpreted as evidence of glacial scouring. This is the author's basis for correlating a part of the pre-Animikie erosion interval with the time during which the tillite of the Cobalt series formed.

Brief remarks were made by Messrs. F. F. Grout and C. K. Leith.

CHANGES IN THE GEOLOGIC MAP OF NORTHEASTERN MINNESOTA

BY FRANK F. GROUT AND G. M. SCHWARTZ

(*Abstract*)

Nine or ten changes of more or less importance are noted. The "Coutchiching" schists are shown as equivalent to the Knife Lake slates. The Archean granites are represented only by one large area at Saganaga Lake; other granites are Algomian. The areas of Keewatin greenstone are slightly reduced by separating certain areas of Knife Lake slate, formerly included on account of their green color or alteration to schist. The Rove slate area is reduced and the Keweenawan increased. The Duluth gabbro fingers out on the east into sill-like forms, at least one of which reaches Lake Superior. The red rock area of the gabbro mass is a narrower belt than was supposed, and there is no wide area at the east end. The Keweenawan flows have many intrusive sills, but they are too variable in size to warrant separate mapping either as to age or character of rock.

Presented extemporaneously by the junior author.

Brief remarks were made by Messrs. T. L. Tanton, U. S. Grant, and C. K. Leith, with reply by the author.

ROVE SLATE AREA IN MINNESOTA

BY FRANK F. GROUT AND G. M. SCHWARTZ

(*Abstract*)

Recent work indicates an increase in the number of calcite veins and mineralization toward the east end of the Rove slate area in Minnesota. A map and cross-section of an area of about 40 square miles are shown to indicate the need of further careful study of the area. There are many more diabase sills than the older maps show, but some may have been omitted because of their small outcrop. This increase in the proportion of diabase and its resistance to erosion results in wide exposures of diabase and relatively much smaller areas of slate.

The detailed map suggests a series of peculiar twisted blocks, which may be a form of faulting somewhat unfamiliar to structural geologists.

Presented extemporaneously by the senior author.

CONTRIBUTIONS TO THE GEOLOGY OF THE CUYUNA RANGE

BY GEORGE A. THIEL

(*Abstract*)

Since the discovery of the Cuyuna district one of the most perplexing problems has been the geological succession of the strata and their correlation with known formations of the Lake Superior region. The following are some of the diverse opinions that have been presented:

1. The Cuyuna ore-bearing member, the Deerwood formation, may be equivalent to and coextensive with the Biwabik formation of the Mesabi Range.

2. The ore-bearing formations may be lenses and beds encased in a thick green schist series, composed largely of volcanic materials and clastic sediments now more or less schistose. This group may be a part of the Virginia slate series overlying the Biwabik.

3. The ore-bearing formations of the North Range may be much older than the South Range, with a structural unconformity separating the two.

4. The Cuyuna series may be younger than Upper Huronian, as represented by the Animikian group, and overlap it in the region to the southwest of the west end of the Mesabi Range.

5. A great unconformity may separate the Carlton or Virginia series from the Cuyuna series.

Recent field-work in the region between the Mesabi and Cuyuna ranges gave no evidence of the presence of two unconformable series, but rather a thick layer of residual weathered slate between the drift and solid bedrock.

Magnetic surveys show a general regional attraction over the Virginia slate areas that is less than that in the angle between the two ranges. Several zones of high magnetic variations to the north of the Cuyuna Range have a northwest-southeast trend. Drilling in one of these zones has demonstrated the presence of manganiferous iron ore similar to the brown ores of the Cuyuna Range. A number of ore bodies have been located by exploratory drilling between the Mesabi and Cuyuna ranges, and they are all within the area of greater magnetic variation that connects the two ranges.

A petrographic study of the cherty phases of the Deerwood series shows the presence of greenalite structures and granular chert similar to that of the Biwabik formation. This type of chert has previously been considered characteristic of but one period of Huronian sedimentation in the Lake Superior region, and might be of stratigraphic value. However, Dr. F. F. Grout and Dr. G. M. Schwartz have recently discovered somewhat similar structures in the Rove slate at a considerable distance above the Gunflint formation. It appears, therefore, that the presence of granular chert in the Huronian sediments is not a safe criterion of correlation.

HURONIAN SLATE AREAS OF NORTHEASTERN BARAGA COUNTY

BY L. P. BARRETT

(Abstract)

This paper describes briefly the Huronian sediments on the north flank of the central Archean plateau of Baraga County. The Baraga Archean upland has an average elevation of about 950 feet above Lake Superior. From the north border of this plateau the land slopes down to the shore of the lake and the rapid north flowing streams have cut deep valleys through the glacial overburden and in numerous localities the Huronian rocks on the north flank of the Archean are exceptionally well exposed by river erosion. In several places small gorges afford continuous cross-sections for distances up to a mile in length.

The Huronian rocks rest unconformably on the underlying Archean complex. No Lower Huronian rocks are present and the Middle Huronian is represented only by discontinuous remnants of the white Ajibik quartzite. The Middle and Upper Huronian unconformity is unmistakable, but is not characterized by structural discordance of beds.

The Upper Huronian is essentially a pelite formation with a coarse arkose conglomerate and dark feldspathic quartzite at the base. Just above the quartzite are a series of dark-gray banded slates with interbedded lenses of black siliceous slate and occasionally black graphitic slates. These are associated with narrow lenses of ferruginous slate and iron carbonate rock and heavy chert beds. None of these horizons appears to have any great continuity along the strike, but in general it may be said that there is a zone just above the quartzite characterized by a mixed chemical or organic and mechanical sedimentation. This horizon is the equivalent of the productive iron-bearing formation of the Upper Huronian in Marquette and Iron counties. The bulk of the Upper Huronian consists of graywacke and interbedded slate. For the most part these rocks are a dominant gray color, but include red, green, and purple varieties. The slates are characterized by extremely narrow banding and in places by rapid alternation of fine and coarse sedimentation.

The river sections afford an unusual opportunity for study of folding of the Huronian slates. As a whole the series is characterized by a regional cleavage which strikes from north 75 degrees west to nearly east and west, and dips south at angles varying from 70 to 30 degrees, with an average of perhaps 45 degrees. The observed dips of the bedding are dominantly at low angles to the south, although gentle northward dips are not unknown, particularly near the base of the series, and in many places the rocks are practically horizontal for considerable distances. Locally there are sharp overturned folds which give steep northward or reverse southern dips. In general the Upper Huronian is characterized by broad gentle folds or flexures whose axial planes parallel the regional cleavage and on the superimposed flanks of which are sharp local overturned folds of secondary order.

The thickness of the Upper Huronian series can not be determined exactly. It is believed that it is not much in excess of 1,000 feet and may be less.

The only intrusives in the Upper Huronian are narrow dikes of fresh diabase whose metamorphic effect on adjacent rocks is negligible.

Read by title in the absence of the author.

HASTINGS SERIES

BY M. E. WILSON

(Abstract)

This paper is a preliminary statement of conclusions resulting from a study of the Hastings series carried on during the field seasons of 1920 to 1925.

In 1852 Alexander Murray, of the Canadian Geological Survey, found zones of conglomerate and associated rocks within the Precambrian (Laurentian) basal complex of the Madoc district, in southeastern Ontario, to which the name Hastings series was later given by Sir William Logan. Since Murray's discovery these sediments have been studied by numerous geologists, nearly all of whom came to different conclusions regarding their relationships. In 1920 the writer commenced an examination of the Madoc and Marmora map areas, in which most of the outcrops of the Hastings series occur, and as a result of this investigation has reached the following conclusions:

(1) The Grenville series in the Madoc district consists of lava-flows interstratified with limestone and altered argillaceous sediments.

(2) The Hastings series rests unconformably on the Grenville series, but the unconformity is probably not of regional importance or part of a palæoplain, for (*a*) there is no observable discordance in dip between the rocks of the Grenville and Hastings series; (*b*) where the rocks of the Hastings series are in contact with granite, the latter is intrusive in its relationships, and (*c*) the writer was unable to find any true pebbles of granite in the Hastings series or other evidence that the Grenville series was intruded by granite before the Hastings series was laid down.

(3) The structure of the rocks of the district show that the interesting and peculiar "blue limestone" that occurs so extensively in the region is a part of the Hastings series and overlies its conglomerate, graywacke, and argillite members.

(4) The buff weathering dolomite, fragments of which are included in the Hastings conglomorate, occurs in several beds, part of which belongs to the Grenville series and part to the Hastings series.

GEOLOGICAL RECONNAISSANCE IN THE PIEDMONT OF VIRGINIA

BY A. I. JONAS

(Abstract)

In 1926 the writer began a reconnaissance of that part of Virginia which lies between the Coastal Plain and the western front of the Blue Ridge, and the results so far obtained are briefly as follows:

The crystalline schists of the eastern Piedmont of Virginia are stratigraphically continuous with Precambrian rocks of the western Piedmont of Maryland. In northern Virginia east of the Triassic sediments the Wissahickon albite-chlorite schist, intruded by granite, diorite, and gabbro, forms an eastern border to the Piedmont. This belt of Wissahickon albite schist lies west of the Peach Bottom syncline, which contains the overlying Peters Creek formation in Pennsylvania and Maryland as far as Sykesville, Maryland.

Southward to northern Virginia granite intrusions interrupt the formation, but it is apparently represented near Palmyra and southwestward. In Maryland and Pennsylvania Peach Bottom slates of supposed late Precambrian age are infolded in the Peters Creek formation. At the James River, in Virginia, Arvonia slates of Chazyan age are infolded in a continuation of the Peach Bottom syncline and northeastward, near Dumfries, slates said to be of Ordovician age are infolded in this syncline.

In Maryland and Pennsylvania the Precambrian Glenarm series, of which the Wissahickon schist and Peters Creek formation are a part, is thrust northwestward over Lower Cambrian arenaceous rocks and Cambrian and Ordovician limestones. This fault, called the Martic overthrust in Pennsylvania, extends to the Potomac River, south of which, to the Rapidan River, it is covered by Triassic sediments. South of Raccoon Ford Wissahickon albite-chlorite schist lies at the eastern contact of blue slaty limestone, which is believed to be the Frederick limestone of Upper Chazyan age. The contact between them is believed to be the southward extension of the Martic overthrust.

A series of normal Triassic faults offset by cross-faults form the border between the Catoctin-Blue Ridge anticlinorium and the crystalline schists and blue limestone belt lying to the east.

The Catoctin-Blue Ridge anticlinorium is composed largely of Precambrian effusives and intrusive igneous rocks with synclinal infolds of Lower Cambrian quartzites. Precambrian sediments are exposed in several places; an anticline of Cockeysville marble extends from the Potomac River to south of Goose Creek; graphitic schists occur in Albemarle County and mica schist in Madison County, thoroughly injected by intrusive rocks, and probably represent part of the Precambrian basement of the anticlinorium.

Read in part by Dr. Wilbur A. Nelson in the absence of the author.

ARE SOME INTRUSIONS REPLACEMENT DEPOSITS?

BY TERENCE T. QUIRKE

(*Abstract*)

The Huronian sediments, which stretch in an almost unbroken belt from the western end of Lake Superior to a line between Killarney and Lake Timiskaming, end abruptly against an area of gneisses.

This area of gneisses, previously thought to be of Laurentian age, is now known to be composed of rocks partly younger than the Huronian sediments, known as the Killarney intrusives, and of highly metamorphosed paragneisses of granitoid composition and of Huronian age.

This paper deals with the development of these granitoid paragneisses. For the most part they are concluded to have been derived from Huronian sediments by a sort of ultra-metasomatism, resulting in regional replacement of quartzite by feldspar on a huge scale. Hundreds of square miles of banded and layered gneisses have been mapped, admitting of no interpretation other than this sort of metamorphism.

Near Killarney particularly favorable outcrops are exposed for observation of the gradual change from dense, white, glassy quartzite through feldspathic

and granitic gneisses into apparently massive granite. Specimens were collected from this locality for examination under the microscope. From a petrographic study of these specimens the means by which this sort of replacement has taken place become evident.

Orthoclase feldspar has penetrated into and crystallized within quartzite by bodily replacement of the quartz grains. There is no evidence of removal of the quartz, but it appears rather as if a cubic unit of quartz had changed in place into a cubic unit of feldspar, illustrating a type of replacement already familiar among the ore minerals to students of economic geology. By a progressive increase in the concentration of the feldspar the rock becomes more and more feldspathic and less quartzitic until it grades into a distinct gneiss with coarse, squarely terminated feldspar phenocrysts. In the extreme phase there are no indications apparent to the naked eye of anything but a massive igneous rock of coarse grain and of syenitic composition. The microscope, however, makes it possible to distinguish remnants of clastic quartz grains even among the coarsest parts of the so-called Killarney granite, all of which near Killarney appears to have been derived from the replacement of quartzite by a progressive increase in the local concentration of feldspar. The same type of quartz grains may be found under the microscope in all specimens, from the non-feldspathic quartzite, through the series of quartzites with increasing quantities of feldspar, to the granitoid gneiss with very little quartz.

Much of the orthoclase has changed partly into microcline, but all of the microcline appears to have been developed originally in the quartzite as orthoclase. In some cases oligoclase-albite includes perthitic growths, and in other cases it has been replaced along the margins by invading areas of orthoclase. Orthoclase itself, once broken, has been cemented by a later growth of orthoclase. The mutual relations of quartz and orthoclase are such that the growth and replacement of these minerals must have continued over a considerable time, with such variations that at different times both quartz and orthoclase were being developed at the expense of the other. In some cases quartz and orthoclase were in a relation so nearly balanced that examples of micropegmatite are fairly common. In spite of such evidences of local equality, the general trend was overwhelmingly in favor of the replacement of quartzite by feldspar.

In the original quartzite there seems to have been very little ferro-magnesian material, and what there is in the Killarney granite and gneisses, a relatively small proportion of the whole rock, appears to have been developed only after considerable quantities of orthoclase had already come into existence; indeed, the feldspars seem to have been the host minerals in which the ferro-magnesian materials have collected.

This replacement of sedimentary rocks by feldspar has involved huge quantities of the Huronian formations. The details of the great and various alterations which have affected different formations will be treated more fully elsewhere; it is the aim of this paper merely to set forth some of the factors so far discovered in the alteration only of the Lorrain quartzite as exemplified in the rocks near Killarney. It may be ventured, however, on the basis of this study, so far as it has been followed, that the end products of all the rocks under contact metamorphism tend to approach the composition of granite.

The writer supposes that many other granitoid masses may have come into existence by a similar regional replacement within the sedimentary crust of the earth. This idea seems at least as probable as that granite batholiths have arisen from still greater depths, deriving their siliceous composition from hitherto unexplained reservoirs in a zone otherwise supposedly basic. Perhaps there is such a process as intrusion by replacement.

Brief remarks were made by Prof. A. C. Lane.

At this point the time for the joint session with the Mineralogical Society had been reached, and the presentation of papers on Precambrian geology was discontinued, to be taken up at a postponed sectional meeting the following day, at which time the additional papers listed below, together with extended discussion of problems of Precambrian correlation, were discussed by many others in attendance, including Messrs. A. C. Lawson, A. C. Lane, Charles K. Leith, W. H. Collins, M. E. Wilson, Arthur E. Seaman, C. L. Dake, R. C. Allen, T. L. Tanton, and Frank F. Grout. The papers listed on this part of the program are inserted in the Minutes at this point.

COUTCHICHING DELTA

BY E. L. BRUCE

(*Abstract*)

The divergence of opinion concerning the relations of sediments of the Coutchiching type and the volcanic rocks of the Keewatin is due rather to the nature of those rocks than to errors in observation. Remnants of ancient terrestrial sediments are found scattered over a wide area. From a central area in northern Manitoba, where the rocks are conglomerate and lie below lava-flows, there is a gradation outward to rocks which were originally sandy or clayey in character. Along the margin of the area the sediments are interbedded with or lie above lavas. It is suggested that this is a great delta and floodplain area in the central part of which sedimentation began long before the volcanic period. At certain places the deposits of the delta margin are interbedded with the lavas.

STRATIGRAPHY OF THE ADIRONDACK GRENVILLE

BY HAROLD L. ALLING

(*Abstract*)

Studies of the graphite deposits in the eastern Adirondack Mountains of New York show that 1,200 feet of Grenville sediments of Precambrian age can be recognized and divided into ten stratigraphic units. Correlation between eight localities situated along a line of section 85 miles long has been attempted on a basis that the graphitic quartz schist, which constitutes the ore, is continuous. This 1,200 feet is only a minor portion of the Grenville sediments present in the Adirondacks. Horizontal variations of a number

of stratigraphic units are discussed with reference to primary sedimentation, degree of subsequent metamorphism, and igneous injection.

Read by title.

AGE OF THE RED CLASTIC SERIES OF MINNESOTA

BY CLINTON R. STAUFFER

(*Abstract*)

The red shales and sandstones occurring below the fossiliferous gray to buff sandstones, shales, and dolomites of the Saint Croix series have been called the Red Clastic series and referred, by Dr. C. W. Hall and others, to the Keweenawan. The outcrop of these rocks is commonly covered by the drift, but some or all of the formations are penetrated by many of the deep wells of the southeastern part of the State. The red shale cuttings brought up from 40 feet below the base of the Hinkley sandstone in the Waconia well contain a fauna which proves these beds to be Middle Cambrian in age. It seems probable, therefore, that the whole deposit may belong to the Cambrian.

ADDRESS OF THE RETIRING PRESIDENT OF THE MINERALOGICAL SOCIETY

At approximately 4 o'clock the joint session arranged with the Mineralogical Society of America was called. The session was opened by the address of Waldemar T. Schaller, retiring President of the Mineralogical Society of America. Title: Mineral replacements in pegmatites.

At the conclusion of this address the additional papers listed for the joint session were presented.

TITLES AND ABSTRACTS OF PAPERS

NATURE AND ORIGIN OF THE "BROWN ROCK" PHOSPHORITES OF TENNESSEE

BY AUSTIN F. ROGERS

(*Abstract*)

The "brown rock" phosphorites, or so-called phosphate rocks of south-central Tennessee, consist largely of the amorphous mineral collophane which has the formula $3\ Ca_3(PO_4)_2.n\ [Ca(CO_3,F_2,O)].(H_2O)_x$, where n is an indefinite number varying from 1 to 2.3 and x is also indefinite. Dahllite, the crystalline equivalent of collophane, with the probable formula, $3Ca_3(PO_4)_2.CaCO_3$, is present in minor amount in some of the phosphorites.

The "brown rock" phosphorites are formed by the weathering and leaching of the calcite from phosphatic limestones of Ordovician age. The phosphatic limestones are made up of angular to rounded fragments of crinoid stems, bryozoans, gastropods (*Cyclora*), brachiopods, ostracods, and ostracoderms. Some of the fragments are entirely calcite, some entirely collophane, but in many the network of the crinoid or bryozoan fragment is calcite and the interspaces or meshes collophane. This mesh collophane of the first

generation was doubtless formed while the fragments were rolled about on the bottom of the sea before consolidation of the limestone.

During the formation of the phosphorites the network calcite was gradually replaced by collophane of the second generation, which has a slightly different refractive index from that of the first generation. The phosphorites contain no calcite, although analyses show from 2 to 4 per cent of CO_2.

At a relatively late stage dahllite was deposited in colloform crusts and occasionally in euhedral crystals, and along with it brown double-refracting collophane of the third generation sometimes appeared. In some specimens the network collophane of the second generation gave place to microcrystalline or "fuzzy" dahllite. In all cases dahllite is a secondary mineral of minor importance.

CALCIUM CHLORIDE WATERS

BY ALFRED C. LANE

(*Abstract*)

In a valuable article on this subject in the Bulletin of the American Association of Petroleum Geologists, 1925, page 1081, Hudson and Taliaferro incorrectly interpret me as believing they are "bitterns," for such are derived from evaporation. They say correctly that I derived them from "a primordial water" that was a weak solution of calcium and other chlorides, but modified, as I thought, by *absorption*, not evaporation, in the Keweenaw waters, and by precipitations, which left the ratio Na : Cl unchanged. I, however, allowed more direct volcanic origin to these waters in part. The "permutit" water softener reaction $CaO.Al_2O_3.2SiO_2 + 2NaCl = Na_2O.Al_2O_3.2SiO_2 + CaCl_2$ might occur and would change the Na : Cl ratio, and that such reactions do occur has been shown by Renick. This makes much more uncertain the argument for increasing Na : Cl ratio. An effect in production of soda-zeolites or albite in the rock containing the waters should occur. While a final decision can only come from a continued critical study of waters, it will be argued that the chemical character of sea-water should have varied, and has. The chemical character of the calcium chloride waters must be studied with regard both to their geological horizon and the character of the containing rocks. There are some indications that waters in rocks largely composed of volcanic ash or rock are more likely to have calcium chloride. It does not appear clear whether this is due wholly to absorption or more or less to leaching. It also appears that there is a similarity in undisturbed connate waters of the same geologic age.

Brief remarks were made by Dr. Charles R. Fettke.

SIGNIFICANCE OF INTERGROWTHS OF CHALCOPYRITE AND CUBANITE

BY G. M. SCHWARTZ

(*Abstract*)

Various explanations have been advanced to account for intimate intergrowths of various metallic minerals. Experiments on the natural minerals have proven that in the case of crystallographic intergrowths of cubanite

($CeFe_2S_3$) in chalcopyrite ($CeFeS_2$) the structure has been developed on cooling by a transformation of a solid solution into two phases. Cubanite characteristically occurs as a bladed or lathlike intergrowth in chalcopyrite. Specimens of this type were polished and sealed in silica or pyrex tubes and then heated in an electric tube furnace. A series of experiments showed that a solid solution of the two minerals would result at a temperature of 475 degrees centigrade held for five hours and quenched. The same specimens were reheated and cooled very slowly—that is, dropped from 500 degrees centigrade to room temperature in 24 to 30 hours—and the two minerals again appeared as an intergrowth, but more minute than in the original.

X-ray diffraction patterns were obtained from powders of the original mixture, the solid solution, and the reprecipitated minerals. These patterns compared with patterns of pure chalcopyrite and cubanite proved beyond a doubt that the two phases were dissolved and then reprecipitated. Attempts to form the solid solution by holding at a temperature of 400 degrees centigrade for a week were not successful. This is interpreted to mean that the material forming the intergrowth was precipitated at a temperature above 400 degrees centigrade. This may be taken as a minimum temperature of deposition for deposits at Fierro, New Mexico; Ducktown, Tennessee; Prince William Sound, Alaska; Parry Sound, Ontario, and Oiseau River, Manitoba, where cubanite occurs as intergrowths in chalcopyrite.

ACTINO-URANIUM AND ENLARGED ANCIENT HALOES

BY T. RUSSELL WILKINS[1]

(*Abstract*)

A new theory of the connection of the actinium series with the uranium series is suggested, in which actinium is considered as coming from an isotope of uranium I. This isotope is taken as having a *shorter* life than uranium I and as having therefore largely disappeared in geological time. It is shown that the generally accepted "branch" origin of the actinium series can not account for the enlargement of the inner ring of pleochroic haloes which Joly has observed in very old biotites, but that just such enlargements would occur on the proposed theory if the parent isotope, actino-uranium I, had a life of about one-twentieth that of uranium I. The new theory appears to clear up, also, certain anomalies which have troubled the physicists.

From the standpoint of the geologists, the proposed scheme has two main points of interest. On such a theory much of the radioactive lead would be actinium-lead, and corrections would be necessary on the ages of rocks determined either from lead or helium ratios. In the oldest rocks this correction apparently amounts to about 40 per cent. Secondly, it seems suggested that the parent elements of the uranium and actinium series had equal alpha-ray activity some 10^9 years ago. This leads to some interesting deductions.

Attempts to find direct experimental evidence of such isotopes are being made. In the nature of the case, the problem is just on the verge of the experimentally possible.

Presented in abstract extemporaneously by Prof. A. C. Lane in the absence of the author.

[1] Introduced by Harold L. Alling and A. C. Lane.

ORIGIN OF CHERT AND FLINT

BY W. A. TARR

(Abstract)

Chert and flint are crypto-crystalline varieties of quartz. Chert is white or light-colored, and flint is black or dark-colored. Their mode of occurrence, form, distribution within the enclosing rock, geologic age, with proof as to time of origin, and geologic distribution, are given.

The theory of the origin of chert and flint presented in this paper is that they were precipitated directly on the sea-floor. Silica, the second most common constituent added by rivers to the sea annually, was more abundant during periods of dominantly chemical erosion, but instead of being deposited as a colloid with shales and clays, as it is largely today, it accumulated. This was aided by hydrophilic colloids, which prevented the coagulation of the silica until the saturation point was reached, when precipitation occurred. The coagulating agent was an oppositely charged ion, which became effective when the hydrophilic ion was neutralized.

The form the silica assumed, its various physical features, its occurrence parallel to the bedding planes, but independent of them, its perfectly preserved fossils, and the faulting and shrinkage cracks it exhibits are believed to be more satisfactorily explained by this theory than by any other.

MICA-PERIDOTITE DIKE IN UNION COUNTY, TENNESSEE

BY C. H. GORDON

(Abstract)

Hitherto, so far as we know, no record has been made of the occurrence of igneous rocks within the Great Valley in east Tennessee. Safford mentions[1] the occurrence in Union County of a "strip" of metamorphic rock composed of "homogeneous, bluish or greenish shale, but mostly made up of a soft dark greenish gray shale abounding in smoky scales of mica and in grains of magnetite." This is now recognized as a mica-peridotite dike, which it is the purpose of this paper to describe.

Union County lies in the middle of the valley of the Tennessee River adjoining Knox County on the north. It is traversed from east to west by the Clinch River, and it is in the valley of a small tributary of this stream which enters it from the northeast that the intrusive rock appears. The surface exposure of the formation occupies an area of about one-half mile in length from northeast to southwest and 30 to 50 yards in width. It follows a prominent fault with Cambrian rocks on the southeast abutting against Silurian and Devonian rocks on the northwest. The stratified rocks of this vicinity have a general dip of about 30 to 35 degrees to the southeast.

The dike rock, which is a highly serpentinized mica-peridotite, has suffered greatly from weathering, the surface down to a depth of 30 feet or more being disintegrated to a flaky, crumbly mass. Aside from the high percentage of serpentine present in the rock, there is a notable amount of

[1] Geology of Tennessee, p. 175.

mica, together with small garnets, magnetite, and secondary calcite and dolomite. Following are two analyses of the rock made in the laboratory of the State Geological Survey:

	SiO_2	Al_2O_3	Fe_2O_3	CaO	MgO	Loss
No. 1	37.76	9.32	12.44	3.58	21.72	14.64
No. 2	31.38	8.50	14.52	4.90	23.71	17.14

Read by title in the absence of the author.

At the conclusion of this program the session was adjourned, at about 6 o'clock.

Meetings of Monday Evening

PRESIDENTIAL ADDRESS

At 8 o'clock the address of the retiring President, Andrew C. Lawson, was delivered before the combined societies, in the Auditorium of Agricultural Hall. Title: Folded mountains and isostasy. The address is published in full elsewhere in this number of the Bulletin.

ANNUAL SMOKER

At the conclusion of the presidential address, the members of the Geological Society of America and of the affiliated and associated societies and their guests were invited to participate in a complimentary smoker given by the members of the University of Wisconsin connected with geologic science. This function was largely attended and gave excellent opportunity for renewal of acquaintance and for less formal discussions and social enjoyment.

Session of Tuesday Morning, December 28

The morning session was called to order at 9:05 o'clock by President Lawson, in the Auditorium of Agricultural Hall, and proceeded directly to the reading of scientific papers.

TITLES AND ABSTRACTS OF PAPERS

PLEISTOCENE DEPOSITS IN THE EASTERN ALTAI

BY CHARLES P. BERKEY AND FREDERICK K. MORRIS

(*Abstract*)

Pleistocene deposits were found in three localities in the eastern Altai region:

(1) On the north front of the range Baga Bogdo the Hung Kureh formation of late Pliocene age includes fine gravels, gray shaly pond deposits, and wind-blown sands. Overlying the Hung Kureh are the rubbles of the rapidly developing Gochu fan of Pleistocene time, as shown by characteristic fossil content. The Gochu deposition was followed by faulting, tilting, and erosion, followed in turn by the piling up of the high-level Uljitundur fans of late Pleistocene age, which partly buried the upturned remnants of the Gochu and Hung Kureh.

A new erosion epoch supervened and the high-level Uljitundur fans were extensively dissected. In the gaps in their eroded remnants the recent fans have been developed.

Post-Pleistocene deposits include: pond silts; a fill of sand in the Tsagan Nor lowland comparable to the Shabarakh formation of the Djadokhta district; a system of abandoned beaches about lake Tsagan Nor; and a belt of sand-dunes along the southern margin of the lake.

(2) Cirques in the valley heads at Ikhe Bogdo, as well as the glacial gorge and deposits, have been considerably redissected by postglacial streams. A series of rock terraces along the valleys bear rubbles of great boulders let down from the glacial floor which probably corresponds to the highest terrace. Along the foot of the mountain there are tilted fans, high-level fans, and recent fans essentially similar in structure and arrangement to those of Baga Bogdo.

(3) About 30 miles north of Ikhe Bogdo, at Kholobolchi Nor, Pleistocene deposits 20 to 150 feet thick rest on Tertiary sediments. The Pleistocene beds consist chiefly of thick-bedded, fine, buff silts, without shaly parting, and of thin, cross-bedded sands and gravels with fossils of rhinoceros and mastodon.

(4) Other Pleistocene beds, east of Shara Murun, contain abundant shells of a large Corbicula.

Presented extemporaneously by the senior author.

DESERT WEATHERING

BY ELIOT BLACKWELDER

(*Abstract*)

Weathering is a process-complex that converts masses of sound rock into incoherent material suitable for transportation by streams and other agents. After several years of field study, the writer finds himself unable to accept some of the current views about this action as it goes on in deserts. His main conclusions are:

1. By the time they are uncovered at the surface, rocks are already much jointed as a result of diastrophism. This alone produces a copious supply of angular fragments ranging from huge blocks to small chips.

2. Chemical changes, chiefly hydration and oxidation, cause the swelling and mechanical crumbling of the rock. The process does not go so far as to produce true soil, but makes vast quantities of scales, rubble and sand. It is especially effective in feldspathic rocks.

3. Solution, in spite of the low humidity of the desert, causes noteworthy effects on limestone and similar rocks.

4. The wind, although chiefly a transporting agent, abrades rocks to an extent not yet well understood. The effects are conspicuous only where conditions are especially favorable.

5. Frost action is only locally important, and in most places may be disregarded.

6. Stream corrasion of solid rock is a minor process, although streams are very important agents in desert transportation and in land sculpture.

7. Changes of temperature (insolation) do not appear to cause any definite results in rock weathering, even in the desert.

The first two processes (of which only one is true weathering) are believed to be far more effective than all the others combined.

Brief remarks were made by Messrs. M. R. Campbell, Charles P. Berkey, John P. Buwalda, with reply by the author.

RELATION OF LAKE ERIE TO RECENT AND PRESENT LAND-TILTING

BY FRANK B. TAYLOR

(*Abstract*)

The direction of maximum rise for the Algonquin, Nipissing, and later beaches in the basin of Lake Huron is about north 22 east, and the common hinge line or isobase of zero runs at right angles to this and passes through Grand Bend, Ontario, and about 2 miles north of Richmondville and Standish, Michigan. None of these beaches extends to the basin of Lake Erie. In a review of earlier studies of Dr. G. K. Gilbert and Mr. Sherman Moore (paper presented to Michigan Academy of Sciences, April 1, 1926), the mean rate of rise of the land in the last 2,700 to 3,000 years, including period of gauge readings during the last 50 years, is approximately 1.48 feet per 100 miles per century. Producing the hinge line from Lake Huron to Lake Erie shows that in the same period Buffalo has been uplifted about half a foot a century. The hinge line passes about 4 miles north of Dunkirk, New York, and 32 miles south of Buffalo. Being at the northeast end of the lake, every inch of uplift at Buffalo raises the water level of the whole lake. South of the hinge line the rise of the water level is the same as the rise of the land at Buffalo. Barring human interference, and supposing the rocksill at Buffalo to hold firm, Lake Erie would be raised to the level of Lake Huron (as it was before the present extreme low stage) in about 1,600 years; and in about 1,600 more the upper four lakes would discharge at Chicago, and Niagara Falls would go dry. At the rate stated, the amount of drowning in Lake Erie south of the hinge line should be 13.5 to 15 feet in the last 2,700 to 3,000 years. Moseley's drowned creek beds on the floor of Sandusky Bay, with other drowned valleys tributary to Lake Erie and Detroit River, indicate a drowning of 12 to 15 feet. These facts strongly support the idea of recent and present tilting of the land at Buffalo at the same rate as that which has affected Lake Huron in the same period. Engineers can hardly afford to overlook these natural changes in planning future works on the shores of these waters.

Brief remarks were made by Prof. A. C. Lane.

MEANING OF MEANDERS IN TIDAL STREAMS

BY MARIUS R. CAMPBELL

(Abstract)

Some years ago the writer became interested in the geomorphic features of the embayed portion of the Atlantic Coastal Plain as represented on the contour maps of eastern Virginia. He was particularly impressed with the fact that, although James River is a tidal stream from a little below Richmond to Newport News, it is characterized not only by meanders, but by cut-off meanders—a feature which was also found at Mount Vernon, 20 miles below Washington.

The consideration of these features led to a study of the behavior of streams when they reach sealevel, and the writer was convinced that tidal streams have no power to initiate or develop meanders, nor have they power or tendency to cut off such meanders, as long as they continue to flow at the level of the body of water into which they debouch.

If this proposition is proved to be correct, it means that another line of evidence is available when considering the geologic history of the Coastal Plain.

Brief remarks were made by Messrs. Frank B. Taylor and John L. Rich.

WORKING CONCEPTS APPROPRIATE TO AN EARTH OF PLANETESIMAL ORIGIN

BY T. C. CHAMBERLIN

(Abstract)

By special permission of President Merriam, separates of a synopsis of earth-growth by the planetesimal method, soon to appear in Year Book Number 25 (1926), Carnegie Institution of Washington, have been printed in advance and distributed exclusively, at this time, to Fellows of this Society to serve as a basis for this paper. Recent critical examination of the inevitable consequences of the close approach of a competent star to our sun shows that it led to dispersion, assortment, and reorganization into orbits about the sun, of that portion of the projected solar material which was lighter and had the higher velocities, while that which was heavier and slower, particularly the metallic portion, was thrown into suborbits, forming a nuclear swarm within its own sphere of control, but which revolved as a whole concurrently with the planetesimals. These orbital motions in both kinds of products forestalled any precipitate ingathering and prevented a molten state except temporarily at the special little spots where the infalls struck.

Both the structural hemispheres and the continental and suboceanic segments were built up very slowly by small mixed accessions in a solid state, in which the metallic element gathered preponderantly toward the center and the lighter factor toward the outer parts. The special modes of growth and the resulting earth structures necessarily gave rise to working concepts radically different from those appropriate to a once molten earth, whatever its

present state of solidity. In a molten earth a superheated condition was inherited and all subsequent processes were governed accordingly, while in a planetesimal earth low temperatures were at first inherited, and the internal heat later developed was the product of compression, reorganization, or diastrophism, as these came into function. Endothermic as well as exothermic action followed, giving rise to peculiar results requiring interpretation on their own special basis.

The mixture of material led to reorganization as pressure and temperature arose from growth as well as concurrent shrinkage. This was progressive so long as growth and shrinkage continued, and resulted in a liquid factor (which was forced toward the surface by differential gravity, tidal kneading, and diastrophism) and a more dense solid factor (which concentrated in the opposite direction). How long it took the deeper liquid products of the later states of increasing pressures and temperatures to reach the surface is not postulated; it is merely held that the liquefying and extruding process is still proceeding and is likely to continue long into the future. This local and temporary production of liquid rock fits the significant fact that heavy and light lavas are poured out high on the continents as well as on the bottoms of the oceans, which under hydrostatic principles inhibits subcrustal connections. The small quantities of lava exuded at any given stage and the graded kinds poured forth were obviously well accommodated to the special conditions at each location and at each stage and were quite free from all regular rhythmical outflows, such as must have arisen from tidal action, if there had been a liquid interior, or substratum, or even large reservoir. Optimum adaptability was a necessary sequence of a growth from planetesimals.

The progressive formation and extrusion of the liquid factor arising from reorganization increased the compactness and solidity of the remaining material and gave rise to shrinkage, attended by the release of potential energy of great competency for megadiastrophic movements; and so, between the great powers of resistance of the deep solid segments wedged together and resting on the still more solid structural hemispheres of the first stage of growth, and the prodigious power of the energies available for forcing yield, there arose a gigantic contest, which has been recorded by baseleveling on the side of resistance and by stages of diastrophic readjustment on the side of prolonged well-controlled yield. At the same time, while dynamic phenomena of the first order of magnitude held steadily on their courses, more or less minor surficial yields took place to satisfy local and relatively shallow stresses. This is precisely what should be expected from interwedged segments of immense strength and power in their deeper parts (which were easily able to promote the major processes), while the special shallower stresses were eased by surficial yield, a two-phase accommodation quite beyond the competency of any "crust" a few tens of miles in thickness resting on a mobile substratum. A brief sketch of the grouping of segments in action and their climatic bearings closes the paper.

SYMPOSIUM ON ZONAL ARRANGEMENT OF METALLIFEROUS DEPOSITS

This portion of the morning session had been set aside for a joint session with the Society of Economic Geologists, and a symposium on zonal arrangement of metalliferous deposits. On account of the crowded time and the wish for more extended discussion, two of the papers listed for this session were carried over to a postponed sectional meeting. The titles, however, are listed in their original order.

ZONAL ARRANGEMENT OF METALLIFEROUS LODES

BY WILLIAM H. EMMONS

ZONAL ORE DEPOSITS OF THE COAST RANGE BATHOLITH

BY S. J. SCHOFIELD

Read by title in the absence of the author.

ZONAL DISTRIBUTION OF ORE DEPOSITS IN CENTRAL EUROPE

BY GEORGE BERG

Read in summary by Prof. Alan M. Bateman in the absence of the author.

RECENT ADDITIONS TO THE EVIDENCE CONFIRMING THE ZONAL ARRANGEMENT OF MINERALS IN THE CORNISH LODES

BY E. H. DAVISON

Read by title in the absence of the author.

TITLES AND ABSTRACTS OF PAPERS

HYPOTHESIS OF BACTERIAL INFLUENCE IN THE GENESIS OF CERTAIN SULPHIDE ORES

BY EDSON SUNDERLAND BASTIN

(*Abstract*)

The work of previous investigators has shown that certain relatively stagnant lake and canal waters and some shallow ground waters are highly charged with hydrogen sulphide as a result of the reduction of soluble sulphates by certain anærabic bacteria. Recent work by the present writer and his collaborators has shown that waters rich in hydrogen sulphide and carrying sulphate-reducing bacteria are associated with petroleum in several of the largest producing oil fields of Illinois and California.

If solutions carrying metals in balance with the sulphate, chloride, or bicarbonate radicles come in contact with such relatively stagnant hydrogen-sulphide-bearing waters, precipitation of the metals as sulphides must result.

Such a mechanism of precipitation is suggested as an hypothesis deserving of critical consideration in future studies of certain types of sulphide ores, such as the "Kupferschiefer," the copper deposits in red beds and other sandstones, and lead and zinc deposits of the Mississippi Valley type.

This paper is published in full in the Journal of Geology, volume XXXIV, 1926, pages 773 to 792.

PONGO DE MANSERICHE, PERU

BY JOSEPH T. SINGEWALD, JR.

(*Abstract*)

The Pongo de Manseriche is the canyon cut through the Eastern Range of the Andes by the Marañon River where it emerges from the Andes into the Amazon Basin. Above and below the canyon the river has a width of 2,000 feet, but in the narrowest part of the canyon its width is reduced to less than 300 feet. The depth of the canyon from the top of the ridge to the level of the river is nearly 3,000 feet, but the highest canyon walls are not over 1,000 feet high.

This part of the Eastern Range of the Andes is an asymmetrical anticline modified on both flanks by faulting. The lowest formation exposed is a massive, white, quartzitic sandstone that forms the highest canyon walls. About 1,000 feet of these beds have been cut through by the river. Overlying the sandstone is a series of shale and limestone strata about 3,500 feet thick that ranges in age from Albian to Coniacian. Sandstone beds of appreciable thickness are also included in the series, most abundantly near the top and bottom. The next younger division of strata are the Red Beds. The top of the series is not exposed on either limb of the anticline. On the east limb are about 4,000 feet of Red Beds and on the west limb about double that amount. These beds have generally been regarded as Tertiary, but their conformability with the underlying beds indicates they are in part at least Upper Cretaceous. A still younger series of Tertiary beds are in discordant contact with the Red Beds on both limbs of the anticline. They consist of friable sandstone and clay-shale of various colors. At least 1,000 feet are exposed without showing the top or the bottom.

All of the above strata were involved in the orogenic movements of the Eastern Range. A younger group of strata that are later than this folding is represented by the Pliocene beds of Pebas. These data fix the age of the Eastern Range with reasonable certainty as late Miocene.

At the conclusion of this part of the program, the session adjourned for luncheon.

Session of Tuesday Afternoon

The afternoon session was called to order at 2.07 o'clock, in the Auditorium, with President Lawson in the chair, who announced a joint session with the Paleontological Society.

TITLES AND ABSTRACTS OF PAPERS

DEVONIAN SECTION IN THE SANTA RITA MOUNTAINS OF ARIZONA

BY CLINTON R. STAUFFER

(*Abstract*)

During a recent study of the Devonian of southern Arizona, an unusual thickness was found in the Santa Rita Mountains just south of Greaterville. A careful measurement of the section showed 1,550 feet of hard dark-gray to black limestone with some shales. While the upper 300 feet carry the familiar fossils, the balance of the limestone is mostly barren except the lower third, which was found to contain a fauna very different from that of the usual Martin limestone and at once marked it as much older. This lower fauna somewhat resembles that found by Kindle in the Jefferson limestone of Montana, although it has a greater variety of Mollusca and fewer Brachiopoda. The formation carrying this older fauna in Arizona may be called the Santa Rita limestone, and its age is probably Middle Devonian.

Read by title.

STRATIGRAPHY AND PALEONTOLOGY OF THE PENNSYLVANIAN OF NORTHWESTERN ILLINOIS[1]

BY H. R. WANLESS[2]

(*Abstract*)

The chief coal of the Alexis Quadrangle, located in the Rock Island district, in northwestern Illinois, outcrops in a number of local basins in the northern and southern parts of the area. It has been correlated with the old number 1 coal of the Worthen Survey. The limestone cap rock containing the fusulinid *Girtyina ventricosa*, which normally overlies this coal, is separated from it in depressions in the coal basin by from less than one inch to 30 inches of black, fissile shale. In this shale is a marine fauna and scattered through it are large lime concretions, or "niggerheads," in which are found extensive brachiopod and molluscan faunas. This "niggerhead" shale horizon was not previously known in connection with the Rock Island coal. The species *Spirifer rockymontana*, which is generally considered a reliable index fossil of Pottsville formations, is present in the limestone cap rock and the shaly limestone overlying it. In the cap rock occurs a small fusulinid apparently closely related to *Girtyina ventricosa*, the latter having been considered indicative of the

[1] Courtesy of the Chief of the Illinois State Geological Survey.
[2] Introduced by W. S. Bayley.

cap rock of number 6 coal in Illinois. Culver recently used detailed lithologic comparisons in support of the theory that the coal of this district may be correlated with the number 6 coal. On the basis of the abundance of typical forms of *Girtyina ventricosa* in the limestone cap rock of the Milan-Edgington area, Savage also interpreted the associated coal to be number 6 coal.

In the same area, at levels from 80 to 120 feet higher, occurs a thinner, essentially horizontal coal having a position in an unusual stratigraphic sequence, which heretofore has been considered characteristic of the number 2, or Colchester, coal. Several strata containing marine fossils overlie this coal, among them a series of flattened concretions bearing large numbers of *Aviculopecten rectilaterarius*, which normally occurs in such concretions in the same position between the number 2 and number 5 coals.

The conclusions arrived at are:

1. The lower coal seam of this district, which has recently been correlated with the number 6 coal at the top of the Carbondale formation, appears to be older than a basal Carbondale coal and may be called, as it previously was, number 1 coal. These conclusions are not intended to preclude an overlap of the number 6 coal in the immediate Rock Island area.

2. *Girtyina ventricosa*, *Pugnax rockymontana*, and *Myalina swallovi* are here found in the Pottsville formations, although they have been mentioned as limited to younger Pennsylvanian strata in Illinois. The great abundance of the lower Pennsylvanian brachiopod species, *Chonetes mesolobus* and *Marginifera muricata*, and the absence of certain common upper Pennsylvanian forms, such as *Chonetes granulifer*, *Rhipidomella pecosi*, and *Meekella striatocostata*, appear to confirm these conclusions.

Several species, particularly pelecypods, were found which have not been reported before from the Pennsylvanian of Illinois.

CRETACEOUS ROCKS OF THE BOOK CLIFFS IN EASTERN UTAH[1]

BY D. J. FISHER[2]

(*Abstract*)

Rocks exposed in the eastern part of the area described indicate that essentially continuous marine conditions prevailed from earliest Colorado to middle Montana times (Mancos and early Mesaverde of the region). In the western part, increasing in amount toward the west, brackish and fresh-water coal-bearing sediments of Middle and Lower Montana age replace the upper portion of these marine beds.

Brackish and fresh-water sediments, containing coal in the lower part, rest with apparent conformity on the marine beds of the eastern Utah region and, excepting the upper part, carry fossils much like those of the Fruitland, Kirtland, and McDermott formations of the San Juan Basin and in large part like those of the Laramie of the Denver Basin.

The strata of the latest pre-Wasatch formation lie with probable unconformity on the rocks of the brackish and fresh-water series and differ lithologically from them. As these younger rocks were not studied in detail and as no

[1] Published by permission of the Director, U. S. Geological Survey.

[2] Introduced by E. S. Bastin and R. T. Chamberlin.

fossils were collected from them, their exact correlation is unknown. They may be as late as beds designated in other places "post-Laramie" or Fort Union. They are overlain unconformably by conglomerate, sandstone, and vari-colored shales of the Wasatch.

The study here summarized has made available a nearly ideal (east-west) cross-section of the coal-bearing series of a portion of the western part of the Cretaceous Colorado geosyncline. It appears to furnish an excellent illustration of the progressive shifting of the environment productive of coal deposits which results when a great troughlike area or locus of sedimentation is gradually filled.

Brief remarks were made by Dr. M. R. Campbell.

CRETACEOUS ROCKS OF NORTHERN MINNESOTA

BY IRA S. ALLISON [1]

(*Abstract*)

Field-work in connection with an investigation of the water supply and subsurface geology of northwestern Minnesota has yielded important data regarding the distribution of the Cretaceous rocks within the State. The Cretaceous now is known to occur throughout the Red River valley of Minnesota, where a basal sand supplies highly saline waters. Its present extent beneath the high morainic belt east of the Red River valley still is uncertain. Outliers, however, are known as far east as the Cuyuna and Mesabi iron-mining districts. The Cambrian and Ordovician rocks of the extreme northwestern part of the State are overlain by the Cretaceous, so that only the Cretaceous appears on the revised map of that area.

Brief remarks were made by Dr. John B. Reeside, Jr.

SIGNIFICANT BREAKS AND OVERLAPS IN THE PENNSYLVANIAN ROCKS OF ILLINOIS

BY T. E. SAVAGE

(*Abstract*)

The Pennsylvanian rocks in Illinois occupy a basin-like depression, which is deepest in the southeast part of the State. This depression existed in very early Pennsylvanian time, as shown by the fact that Pottsville strata are 800 or more feet thick in southeast Illinois, but along the west and north borders of the Pennsylvanian area the thickness of the Pottsville commonly ranges from zero to less than 100 feet. In these marginal areas the Lower and Middle Pottsville strata are absent.

Besides this general overlap of the Pennsylvanian strata on older rocks in Illinois, there are at least four important sedimentary breaks within the Pennsylvanian system. One of these occurred in late Pottsville time and resulted in the removal of the Seville (number 1) coal and associated strata over considerable areas in the northern part of the State.

[1] Introduced by Frank F. Grout.

The limestone cap rock above the Seville (number 1) coal is here correlated with the Curlew limestone of southeast Illinois and northwest Kentucky. Butts has correlated the Curlew limestone with the Black flint which is the uppermost member of the Pottsville formation in eastern Ohio and western Pennsylvania. Therefore, in order to make the upper boundary of the Pottsville in Illinois correspond with the upper limit of this formation in eastern Ohio and western Pennsylvania, it is here proposed to draw the upper boundary of the Pottsville in Illinois at the top of the cap rock of the Seville (number 1) coal, or at the disconformity present at about this level where the Seville coal and its cap rock are absent.

A second disconformity is present nearly midway between the Colchester (number 2) coal and the Springfield (number 5) bed. This resulted in the erosion of a variable thickness. In some places, all of the shale, 25 to 40 feet thick, that was originally present immediately above the Colchester (number 2) coal was removed.

A third hiatus occurs a short distance below the Herrin (number 6), coal bed, where erosion and the succeeding overlap have permitted the Herrin coal or its limestone cap rock to rest on the truncated edges of lower strata; in places directly overlying the Springfield (number 5) coal, and in others overlapping the larger part, or all, of the Carbondale strata toward the west, where in a few places the Herrin coal or its limestone cap rock rests directly on Pottsville beds.

A fourth important unconformity is present 300 or more feet above the top of the Carbondale formation in eastern Illinois, where a massive conglomerate and sandstone rests on different levels of McLeansboro strata.

Such important unconformities form natural limits for the subdivisions of systems and series and should furnish reliable boundaries for the subdivisions of the Pennsylvanian rocks in Illinois.

MONROE DIVISION OF ROCKS IN OHIO

BY J. ERNEST CARMAN

(Abstract)

The Monroe division of rocks around the west end of Lake Erie has long been considered of Silurian age and was especially so interpreted by Grabau (Michigan, 1910). Later, Stauffer (1916) and Williams (Ontario, 1919) assigned the Upper Monroe to the Devonian. The present paper, based on a study of the Monroe of Ohio, presents the several lines of evidence bearing on the age of the Monroe and concludes that, on the bases of geographical distribution of the members, stratigraphical relations, and faunas, the Upper and Middle Monroe are of Devonian age, the systemic contact in Ohio being at the base of the Sylvania (Middle Monroe) sandstone.

Brief remarks were made by Messrs. Charles Schuchert, W. A. Parks, and Charles R. Fettke.

RED BEDS OF ARIZONA, NEW MEXICO, COLORADO, UTAH, AND WYOMING

BY E. B. BRANSON

(*Abstract*)

The correlation of the Red Beds from State to State is very uncertain. Beds that may be traced with few breaks along the outcrops are called Permian in one place and Jurassic in another. Red bed origin is still an open question. In the same sections with the Red Beds true continental deposits occur and the Red Beds show none of the continental characters by which the other beds are recognized as continental.

The development of extensive thin-bedded deposits is impossible under continental conditions excepting those of extensive swamps. Continental deposits can not have well developed wave ripple-marks and will have only rarely current ripple-marks.

The larger part of the Red Beds is marine. Most of the Chinle was formed as topset beds of deltas. The Pojo Agie beds were found as partially submerged coastal flats and deltas. Very little of the Red Beds can be of æolian origin.

The Jurassic-Triassic line of separation should be between the Pojo Agie beds and the overlying sandstones if the La Plata and Navajo and Wingate are to be classed as Jurassic.

PALEOZOIC AND PRECAMBRIAN GEOLOGY OF UPPER YUKON VALLEY, ALASKA

BY J. B. MERTIE, JR.

(*Abstract*)

The upper Yukon Valley, Alaska, and contiguous areas, show a remarkable sequence of Paleozoic and Precambrian rocks. The Paleozoic sedimentary sequence includes Lower, Middle, and Upper Cambrian, Lower, Middle, and Upper Ordovician, Middle and Upper Silurian, Middle and Upper Devonian, Mississipian, Pennsylvanian, and Permian rocks. The Precambrian sequence consists of schist, gneiss, and related rocks. Acidic and basic volcanic rocks, in part Paleozoic and in part Precambrian, also are present. This paper discusses the lithology and fauna of these formations, their structural and age relations to one another, and attempts to sketch briefly the general geologic history of this region.

ELEPHAS PRIMIGENIUS BOREUS, HAY, IN ILLINOIS

BY A. R. CROOK

(*Abstract*)

Last January a steam shovel loading dirt needed in the construction of United States Government dam number 51, on the Ohio River at Golconda, Illinois, exposed a portion of a tusk of Elephas. Since the men of that community were so helpful, it was possible for the museum, at a trifling cost and in spite of winter weather, to obtain the best representation of *Elephas primigenius*

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(boreus Hay) that has thus far been secured in Illinois. The frontal, nasal, premaxillary, parietal, maxillary, and malar bones give the outline of the head. The left tusk, a portion of the right, three molars, a scapula, femur, portions of other leg bones and ribs furnish a good idea of the animal. Ten ridge plates on a four-inch long grinding surface of molars indicate the species.

The materials were 10 feet deep in alluvial leached sandy clay, probably post-Pleistocene, 35 feet above the Ohio, nearly 350 feet west of river, and 1,400 feet south of dam number 51, 1 mile south of Golconda.

Reexamination of occurrences in Illinois recorded by Hay, Anderson, and others shows eleven examples of this species well established and eight others which have been assigned to this group, but which are now lost without exact measurements having been recorded, or which had 8 or 9 ridge plates, which would place them with *E. columbi*. In Transactions of Illinois Academy of Science, volume XIX, details will be published, giving place and year of discovery, finder, present place of preservation, parts secured, measurements, number of ridge plates, and geological conditions of all occurrences of which the author has any knowledge.

ORDOVICIAN SHALE AND LAVA IN SOUTHEASTERN PENNSYLVANIA

BY GEORGE W. STOSE AND A. I. JONAS

(*Abstract*)

Ordovician shale, called Martinsburg, occurs in a broad belt northwest of the Appalachian Valley, and in several smaller areas called Cocalico, south of this valley and north of the Lancaster Valley. Fossiliferous typical dark-gray Martinsburg shale overlies Chambersburg limestone of lower Trenton and Black River age southwest of Harrisburg. Northeastward the rocks of the main shale belt and of the Cocalico belt differ in lithology from typical Martinsburg in that they contain some red, purple, and green shales, arkosic grits, and red and rusty yellow indurated sandstones. Northeast of Harrisburg they are unconformably on older rocks, resting in places on "cement rock" of Trenton age, on Beekmantown limestone of Canadian age, and on Allentown (Conococheague) limestone of Ozarkian age. This unconformable relation is known to extend northeast of Allentown. The Cocalico shale to the south overlies fossiliferous upper Canadian limestone.

In the vicinity of Jonestown, north of Lebanon, amygdaloidal basalt occurs at the base of the shale, resting on a floor of baked blue limestone, and is overlain by unaltered red sediments which the writers described as probably of Triassic age in an abstract of a paper for the 1924 meeting of the Society. Further study of the area has led them to believe that both the lava flow and the associated overlying sediments are Ordovician and part of Martinsburg deposition, although no fossils have been found in the shale. Cocalico shale to the south, in which Ordovician fossils have been found, contains similar red shale, grits and sandstones, and is interbedded with spotted green and purple shales of probable volcanic origin.

It is concluded that in this part of Pennsylvania, uplift and erosion preceded Martinsburg deposition, and that during this epoch there occurred a volcanic eruption. This period of volcanic activity is synchronous with that which pro-

duced volcanic ash, now preserved in the form of bentonite in central Pennsylvania, in Virginia, Tennessee, Kentucky, and Alabama, and the Jonestown lava may indicate the vent from which some of this ash came.

Read by title in the absence of the authors.

TENTATIVE CORRELATION OF THE PERMIAN OF THE SOUTHERN GREAT PLAINS

BY CHARLES N. GOULD AND ROBIN WILLIS

(*Abstract*)

This paper attempts to set forth certain results of work by various geologists, during the past few years, on the Permian of Kansas, Oklahoma, Texas, and New Mexico.

A tentative correlation is made between the Permian formations exposed along the Pecos Valley, in northeastern New Mexico, the formations outcropping east of the Llano Estacado, in Kansas, Oklahoma, and Texas, and those exposed in Trans-Pecos, Texas.

The key ledge for the Permian of the southern Great Plains region is the Blaine gypsum of Kansas, Oklahoma, and northern Texas, which is tentatively correlated with the San Andres limestone of the Pecos Valley and the Vidrio of the Marathon region.

Presented in abstract extemporaneously by the senior author.

ADDRESS OF THE RETIRING PRESIDENT OF THE PALEONTOLOGICAL SOCIETY

At 4 o'clock the address of Stuart Weller, retiring President of the Paleontological Society, was read in joint session. Title: Paleontology and human progress. This address is published in full in this number of the Bulletin.

At the conclusion of the address the joint session with the Paleontological Society was ended, and a general session was continued in the same room with physiographic and glacial papers.

TITLES AND ABSTRACTS OF PAPERS

TERRACES OF THE HOLSTENSBORG DISTRICT, GREENLAND

BY LAURENCE M. GOULD[1]

(*Abstract*)

In the vicinity of Holstensborg and along the upper reaches of Maligiak Fjord unusually perfect terraces are preserved. In a few cases these terraces are formed in solid rock, but more characteristically they are cut from glacial material. The most interesting series is found at the head of the north arm of Maligiak Fjord beyond the limits of present tide water, and

[1] Introduced by Wm. H. Hobbs.

near the lower end of Taserssuak a large fresh-water lake, which in part occupies the upper end of this fjord valley. These are interesting both on account of the many distinct levels indicated and on account of their morphology. No less than fifteen distinct levels are found here. Futhermore, the changes of water level incident to the formation of this series were caused mainly by an ice-tongue blocking the outlet, in contrast to diastrophic changes, which have been the major cause elsewhere.

Read by title in the absence of the author.

VALLEY DEVELOPMENT

BY E. B. BRANSON

(*Abstract*)

1. Most large streams have taken their courses as extended consequents.
2. Headward cutting is unimportant in determining courses of large streams.
3. Streams tend to meander from their beginning, but develop slip-off slopes rather than flats if they are very swift.
4. Swift streams develop meanders faster than slow ones, but very swift streams develop only moderate curves rather than complete swings.
5. Intrenched streams may develop flats in every meander while they are swift and cutting in hard rock.
6. Slip-off slopes are the normal development of swift streams and in most cases are not the result of rejuvenation.
7. Terraces develop normally at every level of a stream valley and rejuvenated streams have terraces out of harmony in extent and elevation.
8. Rejuvenation causes streams with meanders developed in deep alluvium to carry away the alluvium and straighten the courses.

PHYSIOGRAPHY OF SOME MICHIGAN DUNES

BY IRVING D. SCOTT

(*Abstract*)

The dunes discussed in this paper occur on the east coast of Lake Michigan and consist of rows of great dunes which inclose lagoons of Lakes Algonquin and Nipissing. The history of the dunes is closely associated with the beaches of these lakes, and localities for study were chosen both north and south of the hinge line, the farthest south being Grand Haven.

The dunes occur in narrow ridges of from one-fourth to three-fourths of a mile in width and are composed of apparently irregular sand-dunes that are fixed by vegetation, with the exception of those that are in process of formation or are blowing out. The eastern or lee side consists of a series of arcs of different magnitudes, and the slopes descend abruptly to the lagoon bed or to minor sand hills with little or no transition. The windward side consists of a steep cliff of almost even curvature formed by wave action of the present lake. The cliff is of variable height, the chief characteristic being

the triangular facets of exposed sand where the advancing shore has truncated the windward slope of the dunes.

Within the zone from the cliff eastward the irregularity of the dunes is apparent only. Study shows this zone to consist of dunes of various ages, and that all are to a greater or lesser degree modified by the destructional action of the wind. At the cliff facing the present shore the triangular facets are being blown out in an alarming number of cases. To the west, in succession, are found dunes that are normal except for a shallow trench up the front slope, great horseshoes with deeply trenched front slope which is often compound, followed by a nearly complete trench through the dune area. North of the hinge line the transection and the horseshoe forms are not found except where the Nipissing beach has encroached on the Algonquin.

As a result of this study, the following history may be suggested: 1, Bars were formed and the sand piled into normal longitudinal dunes during Algonquin time; 2, With the recession of the water to Nipissing level the dunes became fixed with vegetation; 3, The dunes were blown out into horseshoe or transection types after the Nipissing shore had advanced and truncated the windward slopes; 4, Subsequent dunes were formed, fixed, and blown out by a repetition of the process during and since Nipissing time; 5, The present blowouts are due to the fluctuation of the present lake level.

Furthermore, the evidence at hand indicates that the dunes did not become detached from their source of supply, and that such small dunes as are found on the dry lagoon bottoms are due to complete trenching by blowouts or to the modification of minor inland beaches. This evidence is not considered conclusive and further work is contemplated.

GLACIAL PHENOMENA IN AND NEAR ALLEGANY STATE PARK, NEW YORK[1]

BY A. K. LOBECK

(*Abstract*)

a. Outwash alluvium filling Allegheny River valley caused a ponding of tributaries outside of glaciated area to form many temporary lakes, a type heretofore not described for this region.

b. Two striking examples of glacial diversion of streams resulting from drift filling are described from the vicinity of Steamburg, New York.

Read by title in the absence of the author.

TERTIARY PHYSIOGRAPHIC DEVELOPMENT OF PORTO RICO AND THE VIRGIN ISLANDS

BY HOWARD A. MEYERHOFF[2]

(*Abstract*)

The physiographic history of Porto Rico was outlined in 1922 by A. K. Lobeck as two early Tertiary cycles of partial peneplanation on a complex

[1] Published by permission of Director, New York State Museum.
[2] Introduced by C. P. Berkey.

mountainous oldland, followed by Oligocene and Miocene coastal plain deposition on the lower of the two peneplains and concluded by differential uplift and deep dissection of all landforms. Recent minor changes of level account for the various coastal features.

More recent studies in Porto Rico and the Virgin Islands indicate that part of the upland of Porto Rico represents, not the older early Tertiary peneplain, as considered by Lobeck, but a late Tertiary erosion level which bevels oldland and coastal plain. This late Tertiary peneplain extends to the northern Virgin Islands (connected with Porto Rico on the east by a shallow submarine platform), where it was incorrectly considered by the writer (in 1926) to represent a pre-coastal plain erosion cycle intermediate between the two identified by Lobeck in Porto Rico. It also extends to Saint Croix, which is separated from Porto Rico and the northern Virgin Islands by a deep of 2,400 fathoms.

The development of the late Tertiary peneplain in Saint Croix, together with the older landforms seen on Porto Rico, strongly implies connection of this island with Porto Rico and the northern Virgin Islands during the denudation of late Miocene and Pliocene time. Uplift of the peneplain apparently occurred before, or at the close of, the Pliocene, and the differential movement was accompanied by the block-faulting which separated Saint Croix from the northern islands, and which was paralleled by block-faulting of major dimensions elsewhere in, and adjacent to, the eastern half of the Greater Antilles.

THREE PLEISTOCENE TILLS IN SOUTHERN MAINE

BY ROBERT W. SAYLES AND ERNST V. ANTEVS

(*Abstract*)

In late July the authors visited a gravel pit located one-third of a mile west of the State road at Elms and two miles south southwest of Kennebunk, Maine. The exposure there revealed two tills in a folded series of gravels and sands. The axes of the folds ran in a direction slightly north of west. The folded series was overlain by the last Wisconsin till, which is not folded, but lies unconformably and horizontally on the eroded edges of the folded series. The lowest member of the exposure is a bed of gravel in layers of coarse and fine pebbles not less than 30 feet thick. The bottom could not be seen. Above the gravel occurs sand about 5 feet thick, and after that a bed of till. It is a typical till about 6 feet thick, with rock-flour and boulders. The rock contents are much weathered. Above the till is a bed of sand and silt about 10 feet thick, and on the other side of the anticline to the left a bed of sand about 5 feet thick. These beds are conformable with the subjacent till in the folding. Above the sand occurs a layer of boulder-clay about 8 feet thick composed of true clay and boulders. This till or boulder-clay also took part in the folding. It was cut off and beveled in the last ice-advance, which left a bed of till the original thickness of which is not known. This uppermost till has rock-flour and sand for a matrix and shows no evidence of having been formed in water. It is inferred that the sea came in after its deposition and

eroded it to its present average thickness, of about 2 feet, at this locality. In some places there is nothing left but gravel, and in other places boulders are found embedded in the matrix.

It is inferred from the structure of this series that the ice which did the folding was the same ice which deposited the second till or boulder-clay. The disturbance consisted chiefly in down-pressing of the beds of the center of the exposure so as to form folds, which appear to run about parallel with the ice-movement. The exact glacial stages of the beds of this formation have not been determined. The deep weathering of many of the pebbles of the formations below the highest till suggests an age older than Wisconsin, possibly Illinoian. Some of the boulders of the Wisconsin till are also deeply weathered, suggesting rehandling by this last ice.

It may be suggested that unless the thick gravel bed was deposited in front of advancing ice, it should be underlain by still another till bed, which would make four in all.

Read by title in the absence of the authors.

GLACIATION OF THE BEARTOOTH MOUNTAINS, MONTANA

BY ARTHUR BEVAN[1]

(Abstract)

The Beartooth Mountains, which are the front range of the Rocky Mountains northeast of Yellowstone National Park, were severely glaciated during Pleistocene time. Two distinct cycles of glaciation are clearly recognized, and there is some evidence of still earlier glaciation.

The significant setting for this glaciation consists of (1) a large anticlinal core of Precambrian crystalline rocks, (2) a northeast-southwest axial divide at altitudes of 12,000 to 12,850 feet, (3) a broad subsummit plateau on the northeast side of this divide, at 9,500 to 11,000 feet above sealevel and 4,000 to 5,000 feet above the adjacent Great Plains, (4) a similar plateau on the southwest slope, and (5) a series of deep, narrow valleys on the northeast slope occupied by tributaries of Yellowstone River.

During the maximum development of the glaciation each of the major valleys on the north and east slopes of the range held a large glacier which was fed by numerous tributaries. Fifteen of these glacier systems existed in the range. The interstream plateaus on the northeast side of the main divide were not glaciated, but nivation was extensive. The plateau on the southwest slope was covered by a broad ice-cap, from which radiated several tonguelike lobes. A few of these lobes moved eastward across the axial divide and descended the valleys to the plains to a minimum of about 4,100 feet.

Among notable effects of glaciation are numerous deep U-shaped canyons and scores of cirques, some of which are elongate crater cirques, a deeply scoured plateau, and huge moraines. Several small glaciers still exist along the northeast side of the main divide.

[1] Introduced by W. S. Bayley.

NEW TILLITE LOCALITY IN WESTERN AUSTRALIA

BY FREDERICK G. CLAPP

(*Abstract*)

At least four pre-Pleistocene epochs of glaciation are known in Australia. They are of Precambrian, Cambrian, Permo-Carboniferous, and probably Cretaceous ages respectively. All of these glacial epochs are well known and recognized by Australian geologists, with the exception of the one last mentioned, evidence of which has been reported previously in only one or two localities. The present paper describes a new locality of this glaciation and gives descriptions of other localities necessary for a clear comprehension of the subject.

Read by title in the absence of the author.

NORTHWEST AND DESERT BASINS OF WESTERN AUSTRALIA

BY FREDERICK G. CLAPP

(*Abstract*)

The continent of Australia has five important artesian basins—the great Artesian Basin, Murray River Basin, Desert Basin, Northwest Basin, and the Coastal Plain Basin of Western Australia. Economic explorations by the writer in 1924 resulted in many interesting discoveries in Desert Basin, Northwest Basin, and the region lying between them. This paper stresses in particular the relations between the two basins and certain new fossiliferous, tillite, and structural localities of interest. The most important point to be emphasized is the close similarity between the two basins—stratigraphically, structurally, physiographically, and historically. It seems apparent that the basins must have been connected in the past, either about the northern end of the intervening Precambrian area or across this area.

Read by title in the absence of the author.

LATE-QUATERNARY CHANGES OF LEVEL IN MAINE

BY ERNST V. ANTEVS

(*Abstract*)

During last summer the writer, partly in the company of Mr. Robert W. Sayles, studied the late-Quaternary changes of level in southern Maine. One of the chief objects was to find out whether the rise of the earth's crust that took place as the last ice-sheet melted was or was not interrupted by sinkings, as was the case in the Saint Lawrence lowland.[1] No undisputable evidence of oscillations in late Glacial time were observed, but the region seems to have undergone a rapid and unbroken uplift till it stood higher relative to sealevel than today. First a few thousand years ago did sinking take place, establishing the modern relation between land and sea.

[1] Antevs: Geol. Survey of Canada, Mem. 146, p. 72; and unpublished studies by J. W. Goldthwait and Antevs.

It is important that the behavior of the earth's crust, as the ice-load diminished and disappeared, was different in the peripheral, intermediate, and central parts of the glaciated areas, and that the upheaval was *not* a simple isostatic process.

Read by title in the absence of the author.

ANNUAL DINNER

At 7 o'clock the Geological Society and its guests, together with the attending members of the Paleontological Society, the Mineralogical Society of America, the Society of Economic Geologists, and the American Association of Petroleum Geologists, assembled in the University Refectory for the annual dinner. There was an attendance of 275 and the appointments were convenient and comfortable. At the conclusion of the dinner, Professor Leith, chairman of the Program Committee and head of the geological staff of the University of Wisconsin, acting as toastmaster, presented the following speakers: Andrew C. Lawson, Arthur Keith, Wilbur A. Nelson, W. E. Wrather, Arthur P. Coleman, E. A. Birge, and T. C. Chamberlin.

TRIBUTE TO JAMES F. KEMP

At a convenient point in the after-dinner program the following memorial Minute in memory of Prof. James F. Kemp, one of the founders of the Society, was read and afterwards sent by wire to the family:

The Fellows and friends of the Geological Society of America, assembled at the annual dinner in Madison, recall the many occasions in former years when Professor Kemp's presence added distinction and grace to these gatherings, and pause for this minute in his memory to send to his family their kindest wishes and deepest sympathy.

Immediately after the reading, the whole assemblage arose and stood in silence for one minute, in an impressive tribute

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SESSION OF WEDNESDAY MORNING, DECEMBER 29

The regular session of Wednesday morning was called to order at 9 o'clock by President Lawson. The report of the Auditing Committee was called for and presented, as follows:

REPORT OF THE AUDITING COMMITTEE

In the absence of the other members of the Auditing Committee, I have audited the accounts of the Treasurer for the fiscal year 1925-1926. The

listed disbursements have been checked against the vouchers and found correct. The income on invested funds has been collected in full for the year. Collections of dues and uncollected dues are as stated in the report. The cash balance as reported by the Treasurer agrees with the bank's statement. The securities in the custody of the Treasurer in Baltimore will be checked by another member of the committee, and report of his findings will be made to the Secretary.

Respectfully submitted, HENRY B. KUMMEL,
Chairman.

This report was received and accepted, conditioned on receipt of an additional section of the report covering the securities.

REPORT ON SECURITIES

The following securities are owned by the Geological Society of America:

10 shares Iowa Apartment House Company stock, number 64.
40 shares Ontario Apartment House Company stock, numbers 65, 210, 279.
2 Texas and Pacific Railway Company first mortgage 5 per cent bonds, numbers 11915, 20892, due June 1, 2000.
2 United States Steel Corporation second mortgage 5 per cent bonds, numbers 2964, 2974, due April 1, 1963.
2 Fairmont and Clarksburg Traction Company first mortgage 5 per cent bonds, numbers 29, 30, due October 1, 1938.
2 Consolidation Coal Company first and refunding mortgage 40-year sinking fund gold 5 per cent bonds, numbers 11850, 11851, due December 1, 1950.
2 Southern Bell Telephone and Telegraph Company first mortgage 5 per cent bonds, numbers M13217, M13218, due January 1, 1941.
2 American Telephone and Telegraph Company 20-year sinking fund 5½ gold debenture, numbers 63305, 63306, due in 1943.
[1]3 Chicago Railways Company first mortgage 5 per cent gold bonds, numbers 20750, 20751, 45871, due February, 1927.
1 Louisville and Nashville Railroad Company 10-year 7 per cent gold note, number M3941, due May 14, 1930.
1 Commonwealth Edison first mortgage gold bond, number 49652, due in 1943.
2 Commonwealth Edison first collateral trust 5 per cent bonds, numbers 8562, 8563, due in 1954.
2 Anaconda Copper Mining Company first mortgage 6 per cent bonds, numbers M100571, M100572, due February, 1953.
2 Baltimore and Ohio Railroad first mortgage 5 per cent bonds, numbers M142100, M142101, due in 1948.
2 Central Railways of Baltimore consolidated 5 per cent bonds, numbers 547, 548, due May, 1932.

[1] Deposited with the Bondholders' Protective Association, certificate of deposit No. 8108.

2 Canadian and Pacific Railway Company 4½ per cent bonds, Temp. numbers TM6305, TM6306, due September, 1946.
2 Westinghouse Electric and Manufacturing Company 5 per cent bonds, numbers TM21735, TM5324, due September, 1946.
2 Bethlehem Steel Corporation 6 per cent bonds, series A, Temp. numbers 14758, 24088, due August, 1927.
5 City of Philadelphia 4 per cent loan, numbers 2862, 2863, 2864, 2865, 2866, due February 1, 1953.

The securities on this list have been examined, together with their proper coupons, and found correct on February 8, 1927.

EDWARD W. BERRY.
G. F. LOUGHLIN.

The report of the Council, which had been laid on the table pending approval of the Auditing Committee, was then formally adopted.

TITLES AND ABSTRACTS OF PAPERS

SAINT PETER SANDSTONE IN ILLINOIS: SOME PERTINENT NEW FACTS[1]

BY J. E. LAMAR[2]

(*Abstract*)

Certain facts of interest have come to light from a recent field and laboratory study for the Illinois Geological Survey of the geology and economic resources of the Saint Peter sandstone in Illinois. These bear chiefly on the structural and textural features of the Saint Peter sandstone and include discussions and illustrations of the following: ripple-marks, cross-bedding, worm borings, sun-cracks, pitting of the sand grains resulting from the solution of and deposition of silica, and textural variations locally and regionally and their relation to the source of the sand.

Brief remarks were made by Messrs. F. W. Sardeson, C. L. Dake, and Charles P. Berkey.

MISSISSIPPI RIVER GRAVELS BELOW THE MOUTH OF THE ARKANSAS RIVER

BY MAX LITTLEFIELD[3]

(*Abstract*)

Gravels of uniform size occur on bars between the mouths of the Arkansas and Red Rivers. Below the mouth of the Red River the quantity and size of the gravel decreases, except where the river crosses the Citronelle formation, and no gravel was found in the lower 150 miles of the river.

The probable sources of the gravels are: valley fill and underlying formations and the upper river.

[1] Courtesy of the Chief, Illinois Geological Survey.
[2] Introduced by M. M. Leighton.
[3] Introduced by A. C. Trowbridge.

DISPOSAL OF SEDIMENTS CARRIED TO THE GULF OF MEXICO BY SOUTHWEST PASS, MISSISSIPPI RIVER

BY A. C. TROWBRIDGE

(*Abstract*)

As one of several units in a study of the acquisition, transportation, and deposition of sediments by the Mississippi River and its tributaries, 541 out of 547 samples collected by the United States Coast and Geodetic Survey between June 1, 1921, and July 1, 1922, from the bottom of the Gulf of Mexico over an area of 600 square miles near the mouth of Southwest Pass, at depths of 3 to 250 fathoms, and referred to the writer by the United States Geological Survey, have been analyzed in the Sedimentation Laboratory at the University of Iowa.

The analytical work was done by Dr. Max Littlefield as research assistant to the writer. Supervisory assistance was given by Prof. A. O. Thomas in connection with the study of the life forms.

The purpose was to secure data on the disposal of sediments carried to the Gulf by this largest mouth of the river, and thus, perhaps, to arrive at an idea of the nature of ancient marine sediments deposited at or near the mouths of rivers.

The results of study of the samples are shown on a series of sediment maps, which indicate: 1. That the largest grains carried to the Gulf by the river are one-half to one-fourth millimeter in diameter; 2. That these largest grains are all deposited on the crest of the offshore bar or are found in the beaches on the sides of the pass lands; 3. That few grains one-fourth to one-eighth millimeter in diameter are carried farther than 3 miles out from the pass mouth or from the beaches; 4. That the material of the offshore bar is coarser than any of the beaches; 5. That the finest sediments are in the deepest water southeast of the pass mouth; 6. That there is, 22 miles straight out from the pass mouth, an area over which the water is 32 fathoms deep, although water closer to the pass mouth is 50 fathoms deep, on which the sediments are coarser than anything in either bar or beach, which sediment is believed not to have been contributed by the present river; 7. That all the grains are angular or show what appear to be glacial markings, being below the size limit of effective rounding by water; 8. That the minerals in the sediment are many and varied, indicating that much of it comes from the glaciated areas to the north; 9. That there is glauconite on the outer steep slope of the Gulf bottom; 10. That, except for shell fragments on the beaches, a zone of about 3 miles radius from the pass mouth appears to be practically without life or organic remains; in a zone 3 to 8 miles out there are agglutinate and chitinous foraminifera; beyond this there are calcareous foraminifera and beyond 10 miles pelagic forms constitute a portion of the bottom sediment; 11. That on the outer shoal mentioned in 6 above, there are shell fragments and complete shells of gastropods and pelecypods; also parts of sea-urchin tests and bits of coral. On some of these specimens brought up by the sampler are colonies of living bryozoa. Many of the shells are solution-pitted.

UNUSUAL STRUCTURAL FEATURE IN THE PLAINS REGION OF TEXAS

BY E. H. SELLARDS

(*Abstract*)

The paper describes a new structural feature in the High Plains region of Texas. The locality is in Ector County, 7 miles southwest of the town of Odessa. At this locality there is found a pit, or crater, approximating a circular form, although with a slight northeast-southwest elongation, together with some irregularities in the marginal outline. The rim of the crater rises from 5 to 7 feet above the general level of the surrounding plain. The depression is to some extent filled by wash and wind-blown material, the depth being at present not more than 10 feet below the rim or 5 feet below the average of the surrounding plain. In width from rim to rim the depression measures about 600 feet. At this locality some meteorite fragments have been found, which, together with the form and character of the depression, suggest the possibility of this crater having been formed by a meteorite striking the earth. These fragments are of an iron meteorite, a description and analyses of which have been given by Merrill in the American Journal of Science, volume III, page 339, 1922.

In the rim of the crater the rock strata dip at a high angle, abrupt small folds and offsets being observed. At places on the side of the crater there is found exposed not only the surface rock of this region, which is Pleistocene in age, but also the underlying Cretaceous strata, these having been sufficiently elevated to become exposed.

Five possible methods of the formation of this structural feature are discussed, as follows: 1, A volcanic explosion; 2, A salt dome; 3, The slow upward pressure exerted by hydration of minerals; 4. The explosive escape of gas from within the earth; 5, The explosive rebound from the fall of a meteorite.

Between these several hypotheses no conclusive choice can be made at present. The first two are regarded as the least probable, no observations being recorded in this region to support either. Although salt domes are possible, none is known at present in this district. While the strata are upturned at the rim, there is to be seen no accumulation of material ejected from the crater, as would be expected from a volcanic explosion. The hydration of minerals seems an unlikely explanation, notwithstanding that anhydrite altering to gypsum underlies this general region. That hydration should be so localized is doubtful, nor is there found within the crater evidence of the collapsed roof of a dome. With regard to the possibility of the crater being formed by the explosive force of gas, it is to be noted that this locality is in a region in which oil and gas is present. No similar gas explosion, however, is elsewhere recorded in the plains region. It is, of course, possible that the occurrence of the meteorite fragments at this locality, of which at least four have been found, is entirely fortuitous and without significance, so far as this structural feature is concerned. A satisfactory explanation of this crater can probably be obtained, if at all, only by excavating or drilling.

ROLE OF THERMAL STRATIFICATION IN LACUSTRINE SEDIMENTATION

BY E. M. KINDLE

(*Abstract*)

Stratification of the water of most, but not all, small lakes in the Ottawa Valley into three zones is shown by temperature curves representing the summer months. Corresponding contrasts in the hydrogen ion concentration of the surface and deeper waters for the lakes studied is recorded. The temperature graph for one lake represents temperatures taken at approximately monthly intervals from April to November. Certain types of bottom deposits are correlated with the upper and lower zones of thermal stratification.

Laboratory experiments indicating the effect of water stratification in delaying deposition of fine sediments are described. The factor of water stratification is shown to exercise the chief control over the character, quantity, and distribution of organic and calcareous deposits.

Read by title in the absence of the author.

AGE OF FOLDING OF THE WICHITA, ARBUCKLE AND OUACHITA MOUNTAINS, OKLAHOMA

BY SIDNEY POWERS

(*Abstract*)

Recent stratigraphic and paleontologic studies in the Pennsylvanian sediments near the Criner Hills indicate that the Wichita Mountains were folded in early and Middle Pennsylvanian time prior to the deposition of the Deese member of the Glenn formation. The original Wichitas are believed to have extended southeastward past Gainesville, Texas, and to have included the Criner Hills and the many buried hills in this area. The western part of the Arbuckles was folded later, after the deposition of the Glenn formation. The Ouachita Mountains are a series of blocks overthrust from the south, and the date of this overthrusting is believed to have been later than the earliest Pennsylvanian uplift of the Arbuckle Mountains. Later movements in all three areas preceded and followed Permian deposition. The Red River arch in Texas, which extends through Wilbarger County, is probably a part of the Wichita Mountain System.

Brief remarks were made by Messrs. Charles N. Gould and R. C. Moore.

STRIATED BOULDERS ON THE SOUTHERN COASTAL PLAIN OF VIRGINIA

BY CHESTER K. WENTWORTH

(*Abstract*)

Large striated and faceted boulders occurring in the Columbia terrace gravels of the Coastal Plain of Maryland and the District of Columbia have been known for many years. Studies by the writer in 1921 and 1922 extended the known occurrence of these boulders westward up the Potomac River,

through the Harpers Ferry gap, and finally to the margin of the Allegheny Plateau at Cumberland. Scores of localities west of the fall line are now known.

Recent studies of the Coastal Plain of Virginia for the State Survey show that these boulders are not confined to the basin of the Potomac River, but are numerous in the Pleistocene terrace deposits of the James River and are to be found within 15 miles of the North Carolina line. In the James basin they are especially numerous in some of the intermediate terraces at Richmond in situations strikingly analogous to those in which they are found on the Potomac at Washington. No examination has been made of the basin of the Roanoke, the next trans-Blue Ridge River southward from the James, and no southern limit has yet been established for these boulders.

Boulders of foreign materials up to 4 feet in diameter are found near the fall line and up to 2 and 3 feet in diameter within a few miles of Chesapeake Bay, near Point Lookout, on the Northern Neck of Virginia, and in the Hampton Roads district, at the mouth of the James. Many of the more characteristically striated boulders are smaller than the sizes mentioned, but the association and common origin of all these boulders are evident.

That these boulders were ice-borne is strongly suggested by their distribution and by the occasional presence not only of large blocks, but also of blocks of especially fragile material. That they have been striated and faceted by true glacial action the writer is not as yet ready to assert, though he believes that the striations are accomplished through the agency of ice, possibly in rivers under severer conditions than those of the present. Similar striated boulders have not been observed in the load of the present rivers, except as immediately derived from the terrace gravels. Some of the boulders show but a few sporadic scratches, but others are planed and precisely scored in one or several systems of striæ, which seem quite indistinguishable from true glacial work.

It is desired here to call attention to the character and distribution of these boulders rather than to offer a solution for the important problem they present, and it is to be hoped that the interest of geologists will be directed to these boulders, and that the entire extent of their occurrence southward may be learned through the observations of students in other districts.

RELATIONS BETWEEN STRESS, STRAIN, AND RUPTURE IN STRUCTURAL GEOLOGY

BY T. S. LOVERING[1]

(*Abstract*)

After a preliminary discussion of a few simple stress systems and the stress ellipsoid, the theories of rupture depending primarily on stress analysis are considered. Mohr's theory of rupture is shown to be derivable from Johnson's exposition of Navier's theory of rupture.

The strain ellipsoid and Becker's theory of rupture are discussed.

The fundamental assumptions involved in the theories outlined are critically

[1] Introduced by George F. Loughlin.

considered and the entire lack of agreement in results is shown to be due to the different assumptions used as starting points. Any complete theory of rupture must take into account all of these assumptions and would include the following variables: the perpendicular stress component, the shearing stress component, friction, and the state of strain, or amount of elastic deformation preceding rupture.

The physical properties of matter of importance in deformation are discussed and the types of elastic and inelastic deformation are defined and illustrated. The determinants of rupture are then considered and the manner is given in which the angle of rupture is changed by the physical properties discussed earlier. The transmission of force under geologic conditions is considered, and the paper closes with a brief discussion of the following causes of fracturing: simple compression, simple tension, rotational strain, torsion, bending, and friction.

STEEP SUBSURFACE FOLDS VERSUS FAULTS

BY CHARLES T. KIRK AND T. E. WEIRICH

(*Abstract*)

Deep-seated structural conditions—buried mountains, faults and folds—no longer have to await erosion for their discovery and interpretation. In only a few years the drill penetrates thousands of feet deep into and even below bedrocks in thousands of locations, in many localities only a few hundred feet apart. Thus the interpretation of earth movements by means of such subsurface evidence as deep-well logs is now a frequent problem, especially for the petroleum geologist; and inasmuch as oil and gas accumulate chiefly in areas of considerable movement, and complete data as to temperature, cuttings, cores, micropaleontology, etcetera, are obtainable not uncommonly down to a mile deep and in areas remote from surficial evidences of pronounced crustal stress, these data constitute a worth-while contribution to structure studies.

In areas where, for purposes of correlation, it appears necessary to assume dips of more than 20 degrees between near-by wells on formations 3,000 or more feet deep, but directly underlying surface dips of only one-half of one degree, it is common practice to assume that faulting has occurred in the underlying beds. Possibilities of misinterpretation on such subsurface data, however, are ordinarily much greater than met with in surface correlations.

Methods of establishing the presence of both buried folds and buried faults are discussed. The weight of evidence in at least one published account of a supposed buried fault appears to balance in favor of folding; and in general, in spite of the temptation to map a discordance where dips occur just below an unconformity, the burden of proof for faulting is usually greater than for folding in deep-seated rocks.

Read by title in absence of the authors.

STRATIGRAPHIC BOUNDARIES IN GLACIER NATIONAL PARK, MONTANA

BY MARGARET BRADLEY FULLER[1]

(*Abstract*)

A map was presented of the formations found in most of the Lewis Range and in part of the Livingston Range, Glacier National Park. Geological boundaries are based on field studies, party reconnaissance and partly detailed.

The results obtained and the conclusions reached agree, in general, with the findings of R. A. Daly and Bailey Willis in the country to the north. The present survey extends the study south of the area described by the above-named gentlemen and covers a region over 55 miles long and from 5 to 25 miles wide. The main conclusions reached are as follows:

1. The Altyn limestone is represented by only the basal member from Swiftcurrent south to Marias Pass, and this limestone averages less than 700 feet thick above the Lewis overthrust fault.

2. The Appekunny argillite grades up into the Grinnell argillite through a transition zone from two to five hundred feet thick. The Grinnell is a true argillite at the east, but is a massive red and white quartzite west of the great syncline.

3. Field and lithologic relationships warrant the inclusion of the Sheppard formation as the uppermost phase of the Siyeh and not its separation as a distinct formation.

4. The axis of the great syncline, pitching 8 degrees to 10 degrees to the northwest, extends for 30 miles northwest of Marias Pass; the axis then becomes nearly horizontal for about 10 miles and then appears to rise to the northwest as the Canadian boundary is approached. The width of the great syncline becomes less both to the southeast and also to the northwest. An anticline, sharply overturned to the east and well exihibited along the crest of the Livingston Range from Rodgers Peak south to Mount Thompson, marks the western side of the syncline. Along the North Fork of the Flathead the western side of the anticline has dropped from five to eight thousand feet into Flathead Valley, where the fault lies near the head of Lake McDonald. Secondary faulting along the Lake McDonald Valley offsets the main Flathead fault, so that it continues along the South Fork Valley. There is a minor fault north of the Belton Hills.

Brief remarks were made by Dr. M. R. Campbell.

The Program Committee had arranged at this point for a joint session with the Society of Economic Geologists and the American Association of Petroleum Geologists for the presentation of papers of particular interest in the field of applied geology.

The abstracts of these papers follow.

[1] Introduced by U. S. Grant.

NASH SALT DOME: A STUDY IN PROSPECTING BY GEOPHYSICAL METHODS

BY E. DE GOLYER

This discussion was omitted because of the absence of the author.

GREAT SMOKY OVERTHRUST[1]

BY ARTHUR KEITH

(*Abstract*)

The Great Smoky Mountains, a part of the Appalachian Mountains, form the boundary between Tennessee and North Carolina for 60 miles. At the northwestern foot of the mountains lies the Appalachian Valley, in Tennessee.

The valley is underlain mainly by calcareous formations of Lower Cambrian to Carboniferous age; the mountains are formed from siliceous strata of Lower Cambrian age and of Archean granite and gneiss. The Paleozoic column is close to 40,000 feet thick. In the northwestern mountains the great Blue Ridge anticline reaches from end to end of the Appalachians; where it is flanked by the valley structures is found the border fault, here named the Great Smoky overthrust. This has been mapped by the author for 300 miles across Tennessee and into Virginia.

The plane of this overthrust dips gently and is deformed by later folds and faults of great size. Erosion through the thrust-plane now exposes Ordovician rocks in windows surrounded by the overlying Cambrian. No less than ten windows form a chain in the Great Smoky Mountains on a northeast-southwest anticline through Cades, Tuckaleechee, and Wears coves. The rise of this axis to the northeast brings up the fault-plane in a great S curve south of English Mountain in the Mount Guyot Quadrangle, and similar reentrants farther northeast have been described by the author.

At the southeast the thrust-plane passes down into the Archean granite, while at the northwest, or valley margin, it cuts up through the Mississippian limestone. This sets one limit to the age of the overthrust, and another is set by the later folds at the end of the Carboniferous. There need be no great difference in age between the overthrust and the later deformation. Most of the overthrust mass in this district is of Lower Cambrian age. The general rise of axes toward the northeast exposes many Archean and Algonkian rocks in the overthrust mass. The plane is now exposed for 12 miles across the strike, so that, with allowance for later faulting and folding, its width far exceeded 20 miles.

The thrust-plane itself is everywhere covered by hillside wash, but in places contacts are determined within a few feet. Reconstruction of the plane in the Paleozoic rocks shows that it dipped southeastward through them at an average dip of 20 degrees, but it had a somewhat flatter dip in northeast Tennessee. The depth to which the plane descends into the granite is unknown, but was doubtless many miles, for the overriding granites were so deeply buried as to be mashed.

The underlying limestone, on the contrary, is not at all metamorphosed

[1] Published by permission of the Director of the United States Geological Survey.

and is only moderately folded and faulted. In fact, the limestone in the windows is less folded than it is beyond the overthrust. In Tuckaleechee Cove this limestone within 50 feet of the thrust-plane is only cut by little faults, is almost horizontal, and its fossils are not distorted. This scanty disturbance and ease of sliding, even where the overlying load is the entire Paleozoic thickness of nearly 8 miles, plus several miles of granite, is a very striking fact.

Several recent theories of mountain-building require for their operation that the rocks in sliding contact should be specially slippery. The phenomena of this overthrust make it plain that there is no need to postulate special beds of any sort, even in extreme deformation. The phenomena also indicate that the greatest known structures of the crust do not go entirely through it, but are developed in its outer parts and have a strong horizontal component.

Brief remarks were made by Messrs. M. R. Campbell, C. L. Dake, and M. G. Cheney.

At this point President Lawson asked Dr. Arthur Keith to take the chair.

GEOLOGICAL FEATURES OF THE JOHN DAY REGION, EASTERN OREGON

BY JOHN P. BUWALDA

(*Abstract*)

The main features of the geology of the John Day region were described in able fashion by J. C. Merriam twenty-five years ago. Detailed areal mapping and structural and physiographic studies now in progress in the Mitchell and Picture Gorge Quadrangles are furnishing extensive additional evidence corroborating these earlier views.

The formations are a pre-Cretaceous crystalline complex; the Chico, Upper Cretaceous; the Clarno, probably Oligocene; the John Day, Upper Oligocene; the Columbia lavas, Middle Miocene; the Mascall, Middle or Upper Miocene; and the Rattlesnake, Pliocene. Of these only the Chico Cretaceous is marine in origin.

The detailed mapping has brought forth very clear evidence, usually of several kinds, indicating nonconformity between the Chico and the pre-Cretaceous, the Clarno and the Chico, the Columbia lavas and the John Day, and the Rattlesnake and the Mascall. Additional evidence for conformity of the Mascall on the Columbia lavas has been secured.

The Columbia lavas are somewhat unique in this region in the large fraction which fragmental igneous materials constitute in the section. The fissure origin of the lavas is demonstrable at numerous localities.

Faulting of normal type, but generally east-west trend, occurred in post-Mascall pre-Rattlesnake time, but has continued in post-Rattlesnake time. The main features of the physiography have been developed through folding, however; their east-west trend contrasts rather sharply with the dominantly meridional axial directions of the greater ranges to the east and west.

At this point Prof. Charles Schuchert took the chair.

PENNSYLVANIAN SYSTEM IN THE ARDMORE BASIN

BY C. W. TOMLINSON

(*Abstract*)

There were two distinct epochs of Pennsylvanian orogeny in central southern Oklahoma. Intense folding, with great crustal shortening, occurred in a belt 75 miles in width, partly hidden now beneath the edge of the Gulf Coastal Plain, but revealed by drilling.

The later Pennsylvanian orogeny extended farther north toward the continental interior than did the earlier orogeny in the same period.

There is an immense overturned anticline, hitherto overlooked, in the Pennsylvanian area near Ardmore. The discovery of this Overbrook anticline has made possible the complete unraveling of hitherto disputed correlations in this district. It has been fully demonstrated that the Criner Hills of pre-Pennsylvanian rocks stood up as eroding islands in the Pennsylvanian sea, and were completely buried by only the latest Pennsylvanian sediments of this region.

The Permian-Pennsylvanian contact is believed to have been placed much higher in the section in north-central Texas than in northern Oklahoma and Kansas. The position favored in northern Oklahoma for this contact corresponds approximately to the date of the later Pennsylvanian orogeny in southern Oklahoma; but part of the supposedly Pennsylvanian Cisco group of Texas can be traced into Red Beds of southern Oklahoma, which definitely overlie the great angular unconformity recording that orogeny.

POCONO STRATIGRAPHY IN THE BROADTOP BASIN OF PENNSYLVANIA

BY DAVID B. REGER

(*Abstract*)

The Pocono Series of the Mississippian, in the Broadtop Basin of Pennsylvania, contains marine fossils in certain notable exposures of Terrace Mountain and Sideling Hill, as recorded by Ashburner, White, and Stevenson in reports of the Second Geological Survey of Pennsylvania, published in 1878-85. The sections of Ashburner differ so radically from those of White, both in thickness of beds and in fauna, that their relationship has always been problematical.

In 1924 Reger visited the locality, measuring new sections and making new collections, and confirming almost entirely the measurements of White in Terrace Mountain, and at the same time greatly reducing the totals of the Ashburner section in Sideling Hill, and finding further that a more ample collection of marine fossils in Sideling Hill proved this faunal zone to be the same as that of Terrace Mountain.

This formation (named *Riddlesburg Shale*) preserves its lithology northeastward to the Lehigh Valley, but loses its fauna, while southwestward it reappears with a somewhat changed fauna in western Pennsylvania and southwestern Virginia.

Beneath the Riddlesburg Shale a huge red sandstone (*Broad Ford*) is

affirmed as extending from Tennessee to northeastern Pennsylvania and as linking together the Grainger, Price, and Pocono Series. Correlation of the Berea Sandstone of Ohio with the Mount Pleasant of Pennsylvania is indicated.

Near the top of the subjacent Catskill Series of the Devonian a new plant-bearing shale (*Saxton*), containing *Archæopteris*, is announced as covering a wide area of Pennsylvania and West Virginia and throwing more definite light on the Devonian-Mississippian boundary.

Above the Pocono the Trough Creek limestone is correlated in part with the Fredonia and in part with the Gasper of the Mississippi Valley, the lower (Fredonia) part being considered the same as the Loyalhanna. Previous assignments of the Loyalhanna to the Pocono are rejected because of the known existence of about 2,500 feet of strata between the Fredonia and the Pocono, in southern West Virginia and Virgina, but the Loyalhanna-Fredonia correlation of Butts is reaffirmed. Correlation of the Maxville of Ohio with the Gasper and Fredonia, and therefore with Trough Creek, is affirmed, and correlation of the Maccrady of Virginia with the Keokuk of Iowa is suggested.

Read by title in the absence of the author.

EARLY DIASTROPHIC EVENTS IN THE OZARKS[1]

BY C. L. DAKE AND JOSIAH BRIDGE

(*Abstract*)

The facts presented in the following abstract demand reference to the local stratigraphic column, which is herewith appended.

Top	
Thebes-Maquoketa formation	Jefferson City dolomite
Fernvale limestone	Roubidoux formation
Kimmswick limestone	Gasconade dolomite
Decorah formation	Eminence-Proctor dolomite
Plattin limestone	Potosi dolomite
Joachim dolomite	Derby-Doerun dolomite
Saint Peter sandstone	Davis formation
Everton formation	Bonneterre dolomite
Powell dolomite	Lamotte sandstone
Cotter dolomite	Bottom

In the central Saint Francois Mountains the Potosi rests directly on the Bonneterre, the missing Davis and Derby-Doerun wedging into the section to the west, north, and east. In the denuded area local synclines containing Davis and Derby-Doerun demonstrate that the missing formations were deposited over the dome, which was subsequently warped somewhat irregularly, and truncated by erosion in pre-Potosi time. So far as now known, this is the first episode of doming in the Ozarks, of which definite evidence is

[1] Published by permission of the State Geologist.

available. Thus far it has not been recognized outside the Saint Francois Mountain nucleus.

Normally the Gasconade rests on the Eminence, with a distinct basal conglomerate. In the area of the Saint Francois Mountains, however, the older formations are widely removed, and the Gasconade laps across all older beds onto Bonneterre. That the intervening formations once covered the center of the uplift is again indicated by numerous local patches of Potosi in troughs below the Gasconade. This is clearly doming rather than general uplift, because on all sides the Potosi and Eminence wedge into the section in normal development, within a radius of 30 or 40 miles. The active doming again seems to be rather localized in the Saint Francois Mountain area.

At Decaturville the Gasconade is slightly arched and rests across vertical beds believed to be Bonneterre and Davis. The deformation seems to be closely related to the intrusion of a granite boss, which is thus dated as post-Davis and pre-Gasconade.

Important unconformities occur at the base of the Powell and at the base of the Everton, but not enough is known of the distribution of these formations on the west flank of the Ozarks, especially beneath the Mississippian, to indicate local doming at these times.

At Decaturville the Plattin rests directly on the Davis, though local patches of Gasconade prove conclusively that that formation once covered the dome, as did probably also the Roubidoux and Jefferson City. There must, therefore, have been local doming in a pre-Plattin interval.

In the same region, Fernvale rests on the Plattin, with Decorah and Kimmswick missing, though the former presence of Kimmswick is strongly suggested by float carrying *Receptaculites oweni*. Though these conditions do not necessarily imply doming at this time, they do indicate emergence and erosion.

The small patch of Middle Devonian at Rolla, resting on Cotter, implies submergence of at least local embayments, about the beginning of mid-Devonian time, followed by emergence, and their removal before the deposition of the Mississippian. Doming is not necessarily involved.

The widespread distribution of residual Mississippian of several horizons over the Ozarks indicates a much larger area of doming some time prior to that period. That the Mississippian was widely removed from the dome, but not from its flanks, allowing the Pennsylvanian to be deposited extensively on beds as old as Jefferson City or older, seems to indicate post-Mississippian=pre-Pennsylvanian doming over an area much larger than was involved in the earliest movements.

Brief remarks were made by Prof. R. C. Moore.

GEOLOGY OF THE NORTH SHEN-SI BASIN, CHINA

BY MYRON L. FULLER AND FREDERICK G. CLAPP

(*Abstract*)

The paper is a stratigraphic description of the sediments and a discussion of the structure of a basin having an area of about 100,000 square miles and

located in the northern part of Shen-si and adjoining sections of the provinces of Shan-si, Mongolia, and Kan-su.

The region lies in the center of the great loess area of China and, so far as known, had never been previously visited by geologists, and few or no predictions of the nature of the underlying formations had been made, although the Atlas of Baron von Richthofen suggested that "Ueber Carboniferous" rocks would be found extending well into the area.

The loess did not prove as great an obstacle to exploration as anticipated, since most of the larger streams were found to cut through it into the underlying rock, even where the silt mantle was 1,000 feet or more in thickness. The writers' studies established the existence of a great basin occupied by 20,000 feet of consolidated sediments from Cambro-Ordovician to Jurassic in age, with hundreds of feet of Cretaceous and Tertiary gravels in places. About twenty formations or phases were recognized and more than half of them mapped, including three Cambro-Ordovician, one Permo-Carboniferous, one Permo-Triassic, and ten Jurassic divisions, the age assignments being based on subsequent determinations by the China Geological Survey. The results are set forth by a geological map, column and cross-sections, in addition to text descriptions.

The basin is surrounded by folded and faulted uplifts, usually with Archean or Algonkian cores flanked by Cambro-Ordovician limestone. Inside this highly disturbed area, characterized by horsts and grabens as well as by sharp folds, the basin beds proper dip inward toward the center of the trough through a succession of decreasing folds, merging into a westward or northwestward dipping monocline at 25 or 30 miles from the boundary. The beds are not repeated on the western side of the basin, and it is inferred that they abut against a fault of considerable throw.

Read by title in the absence of the authors.

FOSSILS FROM THE WORD FORMATION OF WEST TEXAS

BY JOHAN AUGUST UDDEN

(*Abstract*)

In a diamond-drill core taken in Culberson County, Texas, a small fauna of cephalopods is quite prolific of individuals at some levels in a black shale occurring at from 2,150 to 3,705 feet below the surface. A collection of fossils from this shale has been examined and identified by Dr. Emil Boese. He finds they practically all occur in the Word formation in the Glass Mountains. Since it is evident that these shales are a part of the Delaware Mountain formation, the term "Word" may now be superseded by "Delaware Mountain," which has priority of usage. The identified fossils from the core are listed.

Read by title.

NEW POINTS IN NEW YORK STRATIGRAPHY[1]

BY GEORGE H. CHADWICK

(*Abstract*)

In the mapping of the Catskill Quadrangle in eastern New York, evidence has accumulated of the Ordovician-Silurian angular unconformity at many fresh exposures, and of smaller breaks hitherto unrecognized here between Lower, Middle, and Upper Devonian. Disconformities at top and bottom of the Schoharie member are indicated by glauconite. Pebble-zones and storm-rolled beds cap the Mount Marion (Hamilton) member, with good basal conglomerates in the Ashokan ("Sherburne") and Oneonta. Still more remarkable is the very distinct erosion-surface at top of the Onondaga limestone, which appears to dispose finally of the theory of "contemporaneous overlap" by the Marcellus black shale.

Striking lateral variations occur in the thin Silurian beds beneath the Manlius, especially the replacement of the normal 4 feet of Rondout water-lime by a coarse white sandstone 20 feet thick in a narrow belt, evidently a beach bar. This sandstone has been called "Binnewater" by field parties, but it is clearly above the Cobleskill as determined years ago by Mr. Hartnagel and the writer. The Glenerie (Oriskany) limestone also shows variations into soft dark shales and cherts, the shales carrying a dwarf fauna with ostracods, exposed in recent cuttings.

The structural relations are probably the most complicated of any quadrangle in the State, the mountain folds in miniature described by Davis and by Darton being excessively cut by thrusts and shears. It is likely that this complexity is due to these strata being lifted on the toe of an underlying Ordovician major thrust, on which movement was renewed in the later folding.

Read by title in the absence of the author.

At the conclusion of this paper, about 12.30 o'clock, the session adjourned for luncheon.

SESSION OF WEDNESDAY AFTERNOON

The regular session of Wednesday afternoon was called to order at 2 o'clock by President Lawson, who asked Prof. A. C. Lane to take the chair, so that the President could attend the special meeting of the Council called for this time.

TITLES AND ABSTRACTS OF PAPERS

[1] By permission of the Director of the New York State Museum.

STRUCTURE OF THE THERMAL SPRINGS ON THE WASATCH FAULT

BY FREDERICK J. PACK[1]

(*Abstract*)

There are five major thermal springs on the Wasatch fault. The fault is situated at the western base of the Wasatch Mountains and forms the dividing line between the mountains and a broad sediment-filled valley. Each of the springs is situated at the apex of a sharp mountain spur. Several investigators have suggested that the peculiar location of the springs is probably due to excessive fracturing at these points. Recently it has been observed, however, that the springs are situated uniformly at topographic lows on the fault-line. These lows are necessarily coincident with the apices of the salients because of paucity of deposition within the valley at such places. It is now known that the water ascends from depth (likely along the Wasatch fault) and spreads out into the alluvium on the downthrown block adjacent to the buried fault surface. It saturates the alluvium up to a well-defined level and issues at low points on the fault-line as overflow springs.

Read by title in the absence of the author.

STRUCTURE OF THE MUD BUTTES AND TIT HILLS OF ALBERTA

BY GEORGE SLATER[2]

(*Abstract*)

Examination by O. B. Hopkins of the district in question showed that the Cretaceous beds surrounding the buttes and hills dip gently southward, while in the mud buttes the sediments, disposed irregularly in miniature folds and faulted, dip prevailingly about 30 degrees northeast. The anomalous structure was tentatively explained by Mr. Hopkins as due to pressure of an advancing ice-sheet against an obstructing outcrop which was moved *en masse*, with consequent faulting and folding.

Studies by the writer in 1924 confirm the essential point of Hopkins' view, namely, that the mud buttes and tit hills owe their origin to ice-action; but the detailed relations observed in the field and described in this paper show that these interesting local topographic features are built up by accretions in the form of comparatively thin lenticles of englacial material, the origin being similar to that of deposits investigated at several European points.

Structurally the mud buttes present, from north to south, three zones: (1) Overfolds, forming the highest part of the hills; (2) a zone of compression; (3) bluffs with little compression and no overfolds, this zone being analogous to a horst. But further compression is evident both to the north and south of these zones. Thrust-planes are present in zones 1 and 2, but no tension is indicated. Movement of beds was chiefly north-south, but the structure was built up from south to north.

[1] Introduced by Charles P. Berkey.
[2] Introduced by David White.

The molding of material forming the southern bluffs has been from below upward. The material is composite in character and has been moved as individual ledges or lenticles along thrust-planes. Against the sigmoid curve and associated thrust-plane on the exposed side of the bluffs, which acted as a "horst," the central zone of compressed material has been squeezed, resulting in the formation of overfold diapyre curves, true tectonic folds, and rippling. The upper surface of the central zone finally formed a glide plane for the passage of other material forming zone 1. This material moved in the form of overfolds dissected by thrust-planes, the whole having a radiating structure. The exposed or northern flank formed one of the major thrust-planes of the area. Although the axes have a general east-west trend, there is a slight southerly deflection on the eastern flank, and this is associated with the production of the hummocky area. Pressure was greatest in the center of the area.

This structure plainly is glacial-tectonic. Lenticles of englacial material became incorporated in ice during its southerly passage over Cretaceous strata, and this material, embracing sandstone, etcetera, must have been derived from outcrops in the vicinity, the plane "gumbo" clay to the north forming a suitable floor for ice-movement. Material between two neighboring thrust-planes may be regarded as being moved *en masse*, the average thickness of such lenticles being 20 feet or less. The contortions include (*a*) compression folds due to lateral pressure, and (*b*) flow curves of subsequent deformation by pressure. They display drag (?) phenomena. The association of thin plastic clays with sand offered a most favorable material for incorporation as englacial in a moving body of ice. The structure represents the final stages of the deglaciation of the area, and the structural sequences can be followed when the beds are traced from south to north.

Presented in abstract extemporaneously by Dr. David White in the absence of the author.

COMPOSITION AND STRUCTURE OF THE CASCADE MOUNTAINS IN CENTRAL OREGON

BY EDWIN T. HODGE[1]

(*Abstract*)

The Cascade Mountains south of the Santiam and north of the Middle Fork of the Willamette River present critical evidence in the history of Oregon. After three years of investigation it is now possible to present a preliminary report upon the structure and composition of this area.

The Clarno, John Day, and Columbia River Basalt formations were traced to the canyon of the Deschutes River, where broad open folds and mature surfaces pass under the Cascade Mountains.

On the west side, pyroclastics, similar in composition, relationships, and structure to the John Day formation, were found and traced to the Willamette Valley, where they contain Oligocene fossils. The Miocene Columbia River Basalt formation reappears just west of the divide and forms a maturely

[1] Introduced by W. H. Emmons.

dissected plateau extending to the Willamette Valley. It holds the subsequent Willamette River in place on the soft eastward-dipping Oligocene tuffs.

The Pliocene Mount Jefferson formation, composed of andesitic and trachytic rocks, cuts the older formations, especially near the divide, and fills in the older valleys. It forms the line of high peaks at 121° 45′ longitude and covers the eastern surface for at least 12 miles.

The Black Crater formation underlies glacial drift, covers most of the eastern surface with basalt flows or high volcanoes, and passes under the Deschutes sand.

The Columbia River Basalt, Mount Jefferson, and Black Crater formations all dip gently eastward.

Pleistocene glacial deposits extend from the divide for 25 miles west and 10 miles east.

The Deschutes sand, probably post-Pleistocene, consists of several basalt flows and interflow lake and torrential beds. It lies absolutely flat and covers an immense area north of Bend, east to Prineville, and extends as embayments into the valleys of the Cascades. Flows higher in the Cascade Mountains may be of the same age and origin.

The Crooked River formation partially fills great canyons cut in the Madras formation and has been cut into canyons. In the high Cascade Mountains the drainage is deranged by the recent lavas.

The Cascade Mountains to the north and to the south, in California, have more complex structures and composition. This area merges into one just to the south, where it appears that a simple pile of late Tertiary lavas fills a sag across the Cascade axis. In both areas the structure suggests a block fault dipping gently to the east.

STUDIES IN THE TECTONICS OF THE COAST RANGES OF CALIFORNIA

BY BRUCE L. CLARK

(*Abstract*)

The Coast Ranges of California are essentially block mountains. The primary blocks were formed by faulting before the deposition of the sediments. Basins of deposition were formed as a result of the faulting; the folding is secondary to and the result of compression of the various blocks one against the other. Two types of faults are recognized—primary and secondary. The first represents old shearing planes in the earth's crust; the second is contemporaneous with the folding and was formed by the same compressive forces.

The most important idea brought forth in the paper is that the folding is the result of compression along the fault-lines; that the major primary faults, the compression along which produced the folding, are the result of shearing of the earth's shell brought about by early compression. A large proportion of these shear planes or primary faults are of a Precretaceous origin. Thus the present-day structures in the Coast Ranges are inherited from those of the past; also the present-day pattern of the Coast Ranges is superimposed upon that of the past.

At this point President Lawson resumed the chair.

SCARPS OF THE SOUTHWESTERN SIERRA NEVADA, CALIFORNIA

BY BENJAMIN F. HAKE[1]

(*Abstract*)

The Sierra Nevada, principal mountain range of California, has been generally regarded as a westward tilted fault-block. This conception is the result of studies made principally in the northern portion of the range.

Observations in the southern part seem to demand a modification of this idea. In this part of the Sierra the western slope is not gentle and uniform, as is that of the northern portion, but consists of a series of benchlike plateaus separated by escarpments of notable proportions, which are believed to have been produced by faults of the normal type with downthrow on the western side.

The upper surfaces of the benches are in topographic maturity and deeply soil-covered. The steep slopes which separate them are more youthful topographic features and expose much bare hard rock. The scarps seem to be independent of lithology, and the canyons of the streams which cross them are notably different above and below the lines of the escarpments. The above conditions are strongly suggestive of faulting, and the hypothesis is further strengthened by the presence of crushed zones near the bases of some of the scarps and the landslides and young steep gullies on the faces of others.

The observed escarpments fall into three geographic groups, each composed of three or four escarpments, or zones, along which escarpments occur at intervals. The most northerly group lies between the Merced and Kaweah rivers. It is composed of four zones of escarpments, of which the two larger are each about 40 miles long. The trend of these zones is northwest-southeast, and the displacements are believed to vary between 200 and 1,000 feet. The central group extends from the Kaweah River almost to the Kern. The scarps of this group trend nearly north-south, and displacements as great as 3,000 feet are indicated by the topography. The southern group is in the region about Kern River and is composed of four *en echelon* scarps, which trend northwest-southeast.

A generalized contour map of the Sierra Nevada shows that it is an elongated asymmetrical domelike mass, which slopes downward in every direction from its apex, Mount Whitney. Transverse profiles of the range, selected so as to show the more extensive remnants of the mature topography, distinctly suggest that the older surface has been gently arched.

It is suggested that the Sierra Nevada may have originated as a crustal swell or upwarp produced by deep-seated forces directed upward. Tension produced in the upper crust by this warping caused fracturing and readjustment by normal faulting on both sides of the axial portion of the upwarp. The fracturing on the eastern flank was localized in a narrow zone and produced the well-known fault-scarps of the eastern side of the range. Because the uplift was greater in the southern portion of the range than in the northern, the scarps produced by the western faults are major topographic features of the southwestern part of the range, although they are not recognized and indeed may not exist north of the Merced River.

Read by title in the absence of the author.

[1] Introduced by Bailey Willis.

LABORATORY STUDY IN DELTA BUILDING

BY C. M. NEVIN AND D. W. TRAINER, JR.[1]

(*Abstract*)

This paper describes a series of experiments in delta-building which have been used successfully with classes studying sedimentation. The elements which control the transportation of material by running water and its deposition as a delta are easily illustrated.

The factors controlling the formation of anti-dune ripples and lenses in top-set and fore-set beds are demonstrated. Changing conditions of deposition due to stationary, rising and falling sealevels may be duplicated and their effect on the external and internal structure of the delta is shown.

Read in full from manuscript by the junior author.

Brief remarks were made by Messrs. David White, Frank F. Grout, and John L. Rich.

SHABARAKH FORMATION[2]

BY CHARLES P. BERKEY AND FREDERICK K. MORRIS

(*Abstract*)

In 1925 members of the Central Asiatic Expedition found in central Mongolia a formation which contains artifacts of prehistoric man. The type locality is at Shabarakh Usu, in the broad valley of Djadokhta.

The lower portion of the Shabarakh formation consists of clayey sands and thin, finely bedded sun-cracked clays. The upper portion consists of slightly indurated dune-sand. The visible thickness is about 50 feet, but the configuration of the valley floor suggests a much greater thickness, possibly 200 feet. We interpret the formation as a fill which choked the valley during a period of increasing aridity, when the rain-wash from the valley sides came to exceed the removing competence of the once vigorous stream which finally dried up entirely. This must have accompanied an important change of climate—the last great transition from moist to arid conditions. We judge that it corresponds to the transition from late Pleistocene to Recent time.

Along the southern and western margins the Shabarakh has been dissected by the prevailing westerly winds, as well as by rain-wash, while its eastern (upstream) portion is buried beneath later sands and gravels.

Artifacts of jasper, chalcedony and agate, belonging to late Paleolithic and early Neolithic cultures, are abundant and are associated with fireplaces and fire-broken stones. The lower levels carry material of primitive workmanship resembling the Mousterian types, but the design and quality of workmanship improve in the upper levels. Finally, primitive pottery and ornaments made of fossil eggshells close the series. Similar stone-age cultures

[1] Introduced by Heinrich Ries.

[2] Presented by permission of the American Museum of Natural History.

were found in other deposits believed to be equivalent to the Shabarakh formation.

Presented extemporaneously by the senior author.
Brief remarks were made by Prof. A. C. Lane.

RECENT NEGATIVE SHIFT OF STRANDLINE IN FIJI AND TONGA

BY HARRY S. LADD AND J. EDWARD HOFFMEISTER[1]

(*Abstract*)

Three occurrences are described and compared—Vitilevu, Fiji, and Eua and Tongatabu, Tonga; the first was studied by Ladd, the others by Hoffmeister.

The large island of Vitilevu is almost completely surrounded by a barrier reef. Where this is present there is no clear evidence of any very recent change in the strandline, but on the southwest coast the barrier reef becomes temporarily a fringing reef and evidence indicates that in fairly recent times the sea stood higher relative to the land. The country rock along the coast is a pink limestone, which is capped by a white limestone, the latter appearing as a distinct bench about 4 feet above present high tide. The bench is also developed on small islands close to shore. At one point it is replaced by a lithified sand beach, at another a seacliff is present at the landward edge of the bench. The base of the seacliff is deeply excavated and in the cave thus formed are poorly consolidated but well bedded marine deposits which are abundantly fossiliferous.

The country rock is believed to be Tertiary, the bench limestone is younger. The beach and cave deposits which were formed at the same time as was the bench contain species which seem identical with forms now living in the same area.

The island of Eua, Tonga, shows with equal clearness a recent negative shift of the strandline. Here, also, the western side of the island is bordered by a growing fringing reef, behind which, in many places, is an old fringing reef of recent corals which stands about 4 feet above present high tide. Behind the old fringing reef is a cave-bearing cliff, the cave being 9 feet above present high tide. This cave was made when the old reef was in a living condition. In the bottom of the cave are bedded deposits of coral fragments which are of the same type as the corals in the old reef. Close to this cave is another one about 9 feet higher. This shows a total shift in the strandline of about 18 feet or more. However, the old reef and the lower cave show that for a considerable time the sea stood about 9 feet higher than its present level. Other places along the coast substantiate this. On the eastern and southern side of Tongatabu is a bench 10 to 18 feet above high tide.

The elevated strandline in Fiji is very similar to the younger of the two present in Tonga.

Presented extemporaneously, part by each author.

[1] Introduced by Wilbur A. Nelson.

SPANISH MESETA; A GENETIC MEDLEY OF PLANATION

BY CHARLES KEYES

(*Abstract*)

Over the great central plateau of Spain, La Meseta it is called, where barren conditions present such strong contrasts to the almost tropical luxuriance of the seaboard and remind one of the New Mexican plateau of our own country and the northern Mexican tableland, regional planation appears to be proceeding vigorously, despite present-day dry-climate conditions now prevailing.

The arid cycle in Spain is not so far advanced as it is in America, and there are presented there many features which we do not have at home. If, as is recently urged, the climate of the earth is rhythmic in character, that it is mainly dependent on regularly recurrent astronomical causes, that its extremes return about every 100,000 years, that in one section of a great climatic cycle there is great cold, a veritable ice-age affecting vast tracts of the world, and on the other limb of the cycle excessive heat, a long season of hot, perpetual summer, we are inclined to ascribe the sum-total of present-day erosional effects partly to wind-scour and partly to rain-action. For a long time during a great climatic cycle, a period measurable in tens of millenniums, the wind is dominant; then for an equally long period water gets the ascendency. During the supremacy of the one chief gradational power the lineaments produced by the other are almost entirely, if not quite, affected. It would be difficult at this time to analyze and evaluate the proportional action of each erosional power; but in Spain the possibilities of arriving at tangible results are much more promising than they are in the arid regions of America, where the effects of aridity are so much farther advanced.

Read by title in the absence of the author.

SURPRISE VALLEY FAULT

BY RICHARD JOEL RUSSELL [1]

(*Abstract*)

Surprise Valley, in northeastern California, is a graben between the Warner Range of California and the Hays Canyon Range of Nevada, two typical basin ranges. The Surprise Valley fault, one of the great interlacing fracture-lines of the Great Basin and traced for more than 200 miles, is situated at the base of the Warner Range.

Stratigraphic and geomorphologic evidence indicates that the fault is of the normal, or gravity, type. Numerous exposures of fault-planes accord with this view, eastward dips being noted at angles between 53 degrees and 73 degrees.

In longitudinal profile the highest part of the Warner Range is centrally located. Branches of the Surprise Valley fault outline blocks successively lower both toward the north and south. Horizontal motion of these blocks is

[1] Introduced by A. C. Lawson.

indicated stratigraphically by evidence on fault-planes and by straightness of bordering fault-lines.

Recent escarpments at the base of the Warner Range were studied with considerable care and their positions with reference to the range base were mapped for a distance of 10 miles. The high-water shoreline of a Quaternary lake, Lake Surprise, remains undisturbed in spite of recent faulting associated with the escarpments below, suggesting that the graben is sinking without corresponding uplift of flanking ranges.

Read in full from manuscript.

NON-MARINE TERTIARY DEPOSITS OF COLOMBIA

BY FRANK M. ANDERSON

(*Abstract*)

The Tertiary deposits of Colombia exhibit three distinct facies—marine, estuarine, and lacustrine.

The marine deposits lie along the coast and extend into the valley of the Magdalena to the vicinity of El Banco. Farther south marine influence weakens and finally disappears, the marine deposits giving place first to estuarine and then to purely non-marine beds, which now lie almost entirely far within the mountains. Brackish water beds intervene these and the marine beds of the coast.

In these three provinces are developed parallel sequences of strata throughout the Tertiary. In the marine province the successive series contain characteristic molluscan faunas, from Eocene to Pliocene, while in the other areas there is little direct evidence for age determination. Correlation of the deposits in the various areas can be made only indirectly and upon stratigraphic grounds.

Oligocene deposits have not been proved in the non-marine areas, and later Tertiary deposits have not been differentiated upon the Plateau, though they exist there.

Although geologic disturbances have been frequent and profound in earlier periods, the most important orogenic events occurred in early Pliocene time.

Vulcanism is recognized throughout the Tertiary, beginning in the Eocene and continuing to Pleistocene time, though its most important activity occurred in the early Pliocene, when it was accompanied by extensive faulting and folding of all the earlier strata.

Commercial deposits of petroleum have been found only in the Eocene, or older Tertiary, in both the marine and estuarine areas, especially in the latter, though abundant evidences of its presence are also found in the middle and later Tertiary deposits in the upper stretches of the Magdalena River.

Read by title in the absence of the author.

RESOLUTION OF THANKS

The members of the Geological Society of America in attendance at the Madison meeting wish to express their deep appreciation of the many courtesies which have been shown them on every hand, of the excellent care in rooms and food, of the arrangements which have been made for the scientific sessions, and, above all, of the cordial spirit of welcome shown by the University of Wisconsin, by the Department of Geology, by the Geological and Natural History Survey, and by the people of Madison.

The members of the Society wish also to congratulate the State of Wisconsin on the stimulus given to sound geological investigation by such masters as Irving, Chamberlin, and Van Hise, the high standards of whose work are now being carried forward by the numerous active and worthy successors who have been our hosts at this meeting.

U. S. GRANT,
Chairman.
HEINRICH RIES.
LEWIS G. WESTGATE.

President Lawson then announced that the business, the scientific sessions, and other activities of the annual meeting of 1926 had been completed, and on motion the thirty-ninth annual meeting adjourned at 4 o'clock.

CHARLES P. BERKEY,
Secretary.

Register of the Madison Meeting

FELLOWS

R. C. Allen
Harold L. Alling
R. S. Bassler
Rufus M. Bagg
H. Foster Bain
Edson S. Bastin
Alan M. Bateman
W. S. Bayley
Joshua W. Beede
Charles P. Berkey
Eliot Blackwelder
John A. Bownocker
E. B. Branson
J Harlen Bretz
T. M. Broderick
E. L. Bruce
H. A. Buehler
Bert S. Butler
John P. Buwalda
Gilbert H. Cady
Marius R. Campbell
J. Ernest Carman
Ermine C. Case
Rollin T. Chamberlin
Thomas C. Chamberlin
Bruce L. Clark
Arthur P. Coleman
William H. Collins
Charles W. Cook
Alja R. Crook
Harold E. Culver
C. L. Dake
Carl O. Dunbar
William H. Emmons
A. E. Fath
Charles R. Fettke
August F. Foerste
Sidney L. Galpin
Albert W. Giles
Charles N. Gould
U. S. Grant
Frank F. Grout
W. F. E. Gurley
James H. Hance
W. O. Hotchkiss
Walter F. Hunt
Elbridge C. Jacobs
George F. Kay
Arthur Keith
Cyril W. Knight
Edward H. Kraus
Henry B. Kummel
Alfred C. Lane
Esper S. Larsen
Andrew C. Lawson
Arthur G. Leonard
Morris M. Leighton
Charles K. Leith
Waldemar Lindgren
Armin K. Lobeck
Edward B. Mathews
Warren J. Mead
M. G. Mehl
J. B. Mertie, Jr.
Raymond C. Moore
Wilbur A. Nelson
William A. Parks
R. A. F. Penrose, Jr.
Alexander H. Phillips
Frederick B. Plummer
Sidney Powers
Terence T. Quirke
John B. Reeside, Jr.
John L. Rich
Heinrich Ries
Austin F. Rogers

EDWARD SAMPSON
FREDERICK W. SARDESON
THOMAS E. SAVAGE
WALDEMAR T. SCHALLER
CHARLES SCHUCHERT
ALFRED R. SCHULTZ
GEORGE M. SCHWARTZ
IRVING D. SCOTT
ARTHUR E. SEAMAN
ELIAS H. SELLARDS
PHILIP S. SMITH
EDMUND M. SPIEKER
CLINTON R. STAUFFER
EDWARD STEIDTMANN
WILLIAM A. TARR
FRANK B. TAYLOR
GEORGE A. THIEL
WILLIAM TAYLOR THOM, JR.
ABRAM O. THOMAS
FREDRIK T. THWAITES
CHARLES W. TOMLINSON
ARTHUR C. TROWBRIDGE
WILLIAM H. TWENHOFEL
EDWARD O. ULRICH
FRANK R. VAN HORN
THOMAS L. WALKER
FREEMAN WARD
STUART WELLER
CHESTER K. WENTWORTH
LEWIS G. WESTGATE
DAVID WHITE
M. E. WILSON
ALEXANDER N. WINCHELL
WILLIAM E. WRATHER

FELLOWS-ELECT

ERNEST F. BEAN
ARTHUR C. BEVAN
B. F. HOWELL
RUSSELL S. KNAPPEN
STEPHEN RICHARZ

In addition to the foregoing, there were registered at the meeting 247 members of affiliated and associated societies and visitors.

Lists of former Officers and Meetings, with Dates

By recommendation of the Council, a complete list of past officers, with the dates of their service, is printed in the Proceedings.

PRESIDENTS

1889.	James Hall	1908.	Samuel Calvin
1890.	James D. Dana	1909.	Grove K. Gilbert
1891.	Alexander Winchell	1910.	Arnold Hague
1892.	G. K. Gilbert	1911.	William M. Davis
1893.	J. William Dawson	1912.	H. L. Fairchild
1894.	T. C. Chamberlin	1913.	Eugene A. Smith
1895.	N. S. Shaler	1914.	George F. Becker
1896.	Joseph Le Conte	1915.	Arthur P. Coleman
1897.	Edward Orton	1916.	John M. Clarke
1898.	J. J. Stevenson	1917.	Frank D. Adams
1899.	B. K. Emerson	1918.	Whitman Cross
1900.	G. M. Dawson	1919.	J. C. Merriam
1901.	C. D. Walcott	1920.	I. C. White
1902.	N. H. Winchell	1921.	James F. Kemp
1903.	S. F. Emmons	1922.	Charles Schuchert
1904.	J. C. Branner	1923.	David White
1905.	Raphael Pumpelly	1924.	Waldemar Lindgren
1906.	I. C. Russell	1925.	William B. Scott
1907.	C. R. Van Hise	1926.	Andrew C. Lawson

VICE-PRESIDENTS

(Not including ex-officio Vice-Presidents representing the affiliated Societies)

1889.	James D. Dana	Alexander Winchell
1890.	J. S. Newberry	A. Winchell
1891.	G. K. Gilbert	T. C. Chamberlin
1892.	J. W. Dawson	T. C Chamberlin
1893.	T. C. Chamberlin	J. J. Stevenson
1894.	N. S. Shaler	G. H. Williams
1895.	Joseph Le Conte	Charles H. Hitchcock
1896.	Charles H. Hitchcock	Edward Orton
1897.	J. J. Stevenson	B. K. Emerson
1898.	B. K. Emerson	G. M. Dawson
1899.	G. M. Dawson	C. D. Walcott
1900.	C. D. Walcott	N. H. Winchell
1901.	N. H. Winchell	S. F. Emmons
1902.	S. F. Emmons	J. C. Branner
1903.	Arnold Hague	H. S. Williams
1904.	H. S. Williams	Samuel Calvin
1905.	Samuel Calvin	W. M. Davis
1906.	W. M. Davis	E. A. Smith
1907.	J. S. Diller	A. P. Coleman

1908.	George F. Becker	A. C. Lawson
1909.	Frank D. Adams	John M. Clarke
1910.	Charles Schuchert	A. P. Low
1911.	William North Rice	
1912.	Israel C. White	
1913.	James F. Kemp	R. D. Salisbury
1914.	Waldemar Lindgren	Horace B. Patton
1915.	L. V. Pirsson	H. P. Cushing
1916.	J. P. Iddings	H. F. Reid
1917.	A. C. Lawson	W. D. Matthew
1918.	Bailey Willis	Frank Leverett
1919.	R. A. F. Penrose, Jr.	Herbert E. Gregory
1920.	George P. Merrill	W. G. Miller
1921.	J. B. Woodworth	Arthur Keith
1922.	Henry S. Washington	Robert T. Hill
1923.	W. H. Hobbs	W. H. Emmons
1924.	William A. Parks	Johan A. Udden
1925.	Reginald W. Brock	Marius R. Campbell
1926.	Heinrich Ries	Lewis G. Westgate

TREASURERS

1889–1891.	H. S. Williams
1892–1906.	I. C. White
1907–1917.	W. B. Clark
1917–	E. B. Mathews

SECRETARIES

1889–1890.	John J. Stevenson
1891–1906.	H. L. Fairchild
1907–1922.	E. O. Hovey
1923–	Charles P. Berkey

EDITORS

1890–1892.	W J McGee
1893–	J. Stanley-Brown

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1891.	George M. Dawson	J. C. Branner	
1892.	N. H. Winchell	H. S. Williams	
1893.	E. A. Smith	C. D. Walcott	
1894.	F. D. Adams	I. C. Russell	
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1915.	Charles K. Leith	Thomas L. Watson
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1917.	Arthur L. Day	William H. Emmons
1918.	Joseph Barrell	R. A. Daly
1919.	William S. Bayley	Eugene W. Shaw
1920.	T. W. Vaughan	George F. Kay
1921.	L. C. Graton	G. D. Louderback
1922.	E. S. Bastin	L. G. Westgate
1923.	E. O. Hovey	A. H. Brooks
	Charles Camsell	J. A. Bownocker
1924.	Fred. E. Wright	William H. Twenhofel
1925.	U. S. Grant	Florence Bascom
1926.	Nelson H. Darton	George H. Ashley

ANNUAL AND SEMI-ANNUAL MEETING PLACES

1888. Ithaca, New York.
1889. Toronto, Canada, August.
New York City, December.
1890. Indianapolis, Indiana, August.
Washington, D. C., December.
1891. Washington, D. C., August.
Columbus, Ohio, December.
1892. Rochester, New York, August.
Ottawa, Canada, December.
1893. Madison, Wisconsin, August.
Boston, Massachusetts, December.
1894. Brooklyn, New York, August.
Baltimore, Maryland, December.
1895. Springfield, Massachusetts, August.
Philadelphia, Pennsylvania, December.
1896. Buffalo, New York, August.
Washington, D. C., December.
1897. Detroit, Michigan, August.
Montreal, Canada, December.
1898. Boston, Massachusetts, August.
New York City, December.
1899. Columbus, Ohio, August.
Washington, D. C., December.

1900. New York City, June.
Albany, New York, December.
1901. Denver, Colorado, August.
Rochester, New York, December.
1902. Pittsburgh, Pennsylvania, July.
Washington, D. C., December.
1903. Saint Louis, Missouri, December.
1904. Philadelphia, Pennsylvania, December.
1905. Ottawa, Canada, December.
1906. New York City, December.
1907. Albuquerque, New Mexico, December.
1908. Baltimore, Maryland, December.
1909. Cambridge and Boston, Massachusetts, December.
1910. Pittsburgh, Pennsylvania, December.
1911. Washington, D. C., December.
1912. New Haven, Connecticut, December.
1913. Princeton, New Jersey, December.
1914. Philadelphia, Pennsylvania, December.
1915. Leland Stanford, Jr., University, California, August.
Washington, D. C., December.
1916. Albany, New York, December.
1917. Saint Louis, Missouri, December
1918. Baltimore, Maryland, December.
1919. Boston, Massachusetts, December.
1920. Chicago, Illinois, December.
1921. Amherst, Massachusetts, December.
1922. Ann Arbor, Michigan, December.
1923. Washington, D. C., December.
1924. Ithaca, New York, December.
1925. New Haven, Connecticut, December.
1926. Madison, Wisconsin, December.

OFFICERS, CORRESPONDENTS, AND FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

OFFICERS FOR 1927

President:

ARTHUR KEITH, Washington, D. C.

Vice-Presidents:

CHARLES K. LEITH, Madison, Wis.
DOUGLAS W. JOHNSON, New York, N. Y.
WILLIAM A. PARKS, Toronto, Canada.
AUSTIN F. ROGERS, Stanford University, Calif.

Secretary:

CHARLES P. BERKEY, Columbia University, New York, N. Y.

Treasurer:

EDWARD B. MATHEWS, Baltimore, Md.

Editor:

J. STANLEY-BROWN, 44 Wall Street, New York, N. Y.

Councilors:

(Term expires 1927)

U. S. GRANT, Evanston, Ill.
FLORENCE BASCOM, Bryn Mawr, Pa.

(Term expires 1928)

NELSON H. DARTON, Washington, D. C.
GEORGE H. ASHLEY, Harrisburg, Pa.

(Term expires 1929)

H. FOSTER BAIN, New York, N. Y.
HENRY B. KUMMEL, Trenton, N. J.

MEMBERSHIP, 1927

CORRESPONDENTS

BARROIS, CHARLES, Lille, France. Dec., 1909.
BATHER, FRANCES ARTHUR, London, England. Dec., 1926.
BRÖGGER, W. C., Christiania, Norway. Dec., 1909.
DAVID, SIR TANNATT WILLIAM EDGEWORTH, Sydney, New South Wales. Dec., 1923.
DE GEER, BARON GERHARD, Stockholm, Sweden. Dec., 1910.
DE MARGERIE, EMMANUEL, Strassburg, Alsace, France. Dec., 1921.
HARKER, ALFRED, Cambridge, England. Dec., 1924.
HEIM, ALBERT, Zurich, Switzerland. Dec., 1909.
KAYSER, EMANUEL, Marburg, Germany. Dec., 1909.
KIAER, JOHAN, Christiania, Norway. Dec., 1925.
KOTO, BUNJIRO, Tokyo, Japan. Dec., 1923.
LACROIX, FRANÇOIS ANTOINE ALFRED, Paris, France. Dec., 1923.
LOEWINSON-LESSING, FRANZ J., Leningrad, Russia. Dec., 1926.
MOLENGRAAFF, GUSTAAF ADOLF FREDERIK, Delft, Holland. Dec., 1923.
ROGERS, ARTHUR WILLIAM, Cape Town, South Africa. Dec., 1924.
SOLLAS, WILLIAM JOHNSON, Oxford, England. Dec., 1925.
SEDERHOLM, JAKOB JOHANNES, Helsingfors, Finland. Dec., 1923.
TIETZE, EMIL, Vienna, Austria. Dec., 1910.
VOGT, J. H. L., Christiania, Norway. Dec., 1925.
WALTHER, JOHANNES, Halle-Wittenberg, Germany. Dec., 1926.
WOODWARD, ARTHUR SMITH, London, England. Dec., 1923.

FELLOWS

* Indicates Original Fellows (see article III of Constitution)

ABBE, CLEVELAND, JR., 105 Highland Place, Ithaca, N. Y. August, 1899.
ADAMS, FRANK DAWSON, McGill University, Montreal, Canada. Dec., 1889.
ADAMS, GEORGE I., University of Alabama, Tuscaloosa, Ala. Dec., 1902.
ADAMS, LEASON H., Geophysical Laboratory, Washington, D. C. Dec., 1922.
ADKINS, WALTER S., University of Texas, Austin, Texas. Dec., 1921.
ALCOCK, F. J., Geological Survey of Canada, Ottawa, Canada. Dec., 1920.
ALDEN, WILLIAM C., U. S. Geological Survey, Washington, D. C. Dec., 1909.
ALDRICH, TRUMAN H., 1026 Glen Iris Ave., Birmingham, Ala. May, 1889.
ALLAN, JOHN A., University of Alberta, Edmonton, Alberta, Canada. Dec., 1914.
ALLEN, EUGENE T., Geophysical Laboratory, Washington, D. C. Dec., 1922.
ALLEN, R. C., 1202 Hanna Bldg., Cleveland, Ohio. Dec., 1911.
ALLING, H. L., University of Rochester, Rochester, N. Y. Dec., 1920.
AMI, HENRY M., Victoria Museum, Room 105, Ottawa, Canada. Dec., 1889.
ANDERSON, FRANK M., State Mining Bureau, 2604 Ætna St., Berkeley, Calif. Dec., 1902.
ANDERSON, ROBERT V., Menlo Park, Calif. Dec., 1911.
ANDREWS, E. C., Geological Survey of New South Wales, Sydney, New South Wales, Dec., 1920.

ANTEVS, ERNST V., Geological Museum, Harvard University, Cambridge, Mass. Dec., 1925.

ARNOLD, RALPH, 639 South Spring St., Los Angeles, Calif. Dec., 1904.

ASHLEY, GEORGE HALL, State Capitol, Harrisburg, Pa. August, 1895.

ATWOOD, WALLACE WALTER, Clark University, Worcester, Mass. Dec., 1909.

AURIN, FRITZ L., Marland Oil Co., Ponca City, Okla. Dec., 1925.

BAGG, RUFUS MATHER, JR., 7 Brokaw Place, Appleton, Wis. Dec., 1896.

BAIN, H. FOSTER, c/o Amer. Inst. Mining Engineers, 29 W. 39th St., New York, N. Y. Dec., 1895.

BAKER, MANLEY BENSON, School of Mining, Kingston, Ontario. Dec., 1911.

BALDWIN, S. PRENTISS, 11025 East Blvd., Cleveland, Ohio. August, 1895.

BALL, MAX WAITE, 1104 First Natl. Bank Bldg., Denver, Colo. Dec., 1924.

BALL, SYDNEY H., 42 Broadway, New York City. Dec., 1905.

BANCROFT, JOSEPH A., McGill University, Montreal, Canada. Dec., 1914.

BARBOUR, ERWIN HINCKLEY, University of Nebraska, Lincoln, Neb. Dec., 1896.

BARRETT, LESLIE PARK, Geol. Surv. of Michigan, Lansing, Mich. Dec., 1923.

BARTON, DONALD C., Amerada Petr. Corp., Houston, Texas. Dec., 1921.

BARTON, GEORGE H., Boston Soc. of Nat. History, Boston, Mass. Aug., 1890.

BARTSCH, PAUL, U. S. National Museum, Washington, D. C. Dec., 1917.

BASCOM, FLORENCE, Bryn Mawr College, Bryn Mawr, Pa. August, 1894.

BASSLER, RAY SMITH, U. S. National Museum, Washington, D. C. Dec., 1906.

BASTIN, EDSON S., University of Chicago, Chicago, Ill. Dec., 1909.

BATEMAN, ALAN MARA, Yale University, New Haven, Conn. Dec., 1916.

BAUER, CLYDE MAX, P. O. Box 972, Amarillo, Texas. Dec., 1923.

BAYLEY, WILLIAM S., University of Illinois, Urbana, Ill. Dec., 1888.

BEAN, ERNEST F., Wisconsin Geological and Natural History Survey, Madison, Wis. Dec., 1926.

BEEDE, JOSHUA W., 1201 S. David St., San Angelo, Texas. Dec., 1902.

BEEKLY, ALBERT L., 1106 Cosden Bldg., Tulsa, Okla. Dec., 1925.

BELL, WALTER A., Victoria Memorial Museum, Ottawa, Canada. Dec., 1923.

BENSON, W. N., University of Otago, Dunedin, New Zealand. Dec., 1919.

BERKEY, CHARLES P., Columbia University, New York, N. Y. August, 1901.

BERRY, EDWARD WILBER, Johns Hopkins University, Baltimore, Md. Dec., 1909.

BEVAN, ARTHUR C., University of Illinois, Urbana, Ill. Dec., 1926.

BEYER, SAMUEL WALKER, Iowa Agricultural College, Ames, Iowa. Dec., 1896.

BILLINGSLEY, PAUL, 1027 Continental Natl. Bank Bldg., Salt Lake City, Utah. Dec., 1922.

BLACKWELDER, ELIOT, Leland Stanford Jr. University, Stanford University, Calif. Dec., 1908.

BOUTWELL, JOHN M., Natl. Copper Bank, Salt Lake City, Utah. Dec., 1905.

BOWEN, CHARLES F., c/o Standard Oil Co., 26 Broadway, New York City. Dec., 1916.

BOWEN, N. L., Geophysical Laboratory, Washington, D. C. Dec., 1917.

BOWIE, WILLIAM, U. S. Coast and Geodetic Survey, Washington, D. C. Dec., 1919.

BOWMAN, ISAIAH, American Geographical Society, Broadway at 156th St., New York City. Dec., 1924.

BOWNOCKER, JOHN ADAMS, Ohio State University, Columbus, Ohio. Dec., 1904.

BRANSON, EDWIN BAYER, University of Missouri, Columbia, Mo. Dec., 1911.

BRETZ, J HARLEN, University of Chicago, Chicago, Ill. Dec., 1917.
BRIGHAM, ALBERT PERRY, Colgate University, Hamilton, N. Y. Dec., 1893.
BROCK, REGINALD W., Univ. of British Columbia, Vancouver, B. C. Dec., 1904.
BRODERICK, T. MONTEITH, Calumet and Hecla Mining Co., Calumet, Mich. Dec., 1921.
BROKAW, A. D., 157 Maplewood Ave., Maplewood, N. J. Dec., 1920.
BROWN, BARNUM, American Museum of Natural History, New York, N. Y. Dec., 1910.
BROWN, CHARLES WILSON, Brown University, Providence, R. I. Dec., 1908.
BROWN, JOHN STAFFORD, 520 West Third St., Joplin, Mo. Dec., 1922.
BROWN, THOMAS CLACHAR, Laurel Bank Farm, Fitchburg, Mass. Dec., 1915.
BRUCE, E. L., Queens University, Kingston, Ontario. Dec., 1920.
BRYAN, KIRK, U. S. Geological Survey, Washington, D. C. Dec., 1922.
BUCHER, W. H., University of Cincinnati, Cincinnati, Ohio. Dec., 1920.
BUDDINGTON, A. F., 124 Pyne Hall, Princeton, N. J. Dec., 1919.
BUEHLER, HENRY ANDREW, Rolla, Mo. Dec., 1909.
BURCHARD, E. F., U. S. Geological Survey, Washington, D. C. Dec., 1920.
BURLING, LANCASTER D., Vassar College, Poughkeepsie, N. Y. Dec., 1917.
BURWASH, EDWARD M. J., University of British Columbia, Vancouver, B. C. Dec., 1916.
BUTLER, BERT S., U. S. Geological Survey, Golden, Colo. Dec., 1912.
BUTLER, G. MONTAGUE, College of Mines, Tucson, Arizona. Dec., 1911.
BUTTS, CHARLES, U. S. Geological Survey, Washington, D. C. Dec., 1912.
BUWALDA, J. P., Institute of Technology, Pasadena, Calif. Dec., 1920.
BYBEE, HALBERT P., Dixie Oil Co., San Angelo, Texas. Dec., 1926.
CADY, G. H., Illinois Geological Survey, Urbana, Ill. Dec., 1920.
CALHOUN, FRED HARVEY HALL, Clemson College, S. C. Dec., 1909.
CALKINS, FRANK C., U. S. Geological Survey, Washington, D. C. Dec., 1914.
CAMPBELL, HENRY D., Washington and Lee Univ., Lexington, Va. May, 1889.
CAMPBELL, MARIUS R., U. S. Geological Survey, Washington, D. C. Aug., 1892.
CAMSELL, CHARLES, Department of Mines, Ottawa, Canada. Dec., 1914.
CAPPS, STEPHEN R., JR., U. S. Geological Surv., Washington, D. C. Dec., 1911.
CARMAN, J. ERNEST, Ohio State University, Columbus, Ohio. Dec., 1917.
CARNEY, FRANK, Box 1031, Tulsa, Okla. Dec., 1908.
CASE, ERMINE C., University of Michigan, Ann Arbor, Mich. Dec., 1901.
CHADWICK, GEORGE H., 175 Bridge St., Catskill, N. Y. Dec., 1911.
CHAMBERLIN, ROLLIN T., University of Chicago, Chicago, Ill. Dec., 1913.
*CHAMBERLIN, T. C., Hyde Park Hotel, Hyde Park Blvd. and Harper Ave., Chicago, Ill.
CHANEY, RALPH W., Carnegie Institution of Washington, Berkeley, Calif. Dec., 1926.
CLAPP, CHARLES H., State University, Missoula, Mont. Dec., 1914.
CLAPP, FREDERICK G., 50 Church St., New York City. Dec., 1905.
CLARK, BRUCE L., Bacon Hall, Univ. of California, Berkeley, Calif. Dec., 1918.
CLARK, F. R., 723 Petroleum Bldg., Tulsa, Okla. Dec., 1919.
CLARK, THOMAS H., McGill University, Montreal, Canada. Dec., 1926.
CLARK, W. O., Naalehu, Kau, Hawaii. Dec., 1920.
CLARKE, EDWARD DE COURCY, University of Western Australia, Perth, Western Australia. Dec., 1924.

CLELAND, HERDMAN F., Williams College, Williamstown, Mass. Dec., 1905.
CLEMENTS, J. MORGAN, 20 Broad St., New York City. Dec., 1894.
COBB, COLLIER, University of North Carolina, Chapel Hill, N. C. Dec., 1894.
COLEMAN, ARTHUR P., Toronto University, Toronto, Canada. Dec., 1896.
COLLIER, ARTHUR J., U. S. Geological Survey, Washington, D. C. June, 1902.
COLLINS, WILLIAM H., Geological Survey, Ottawa, Canada. Dec., 1921.
COLONY, ROY JED, Columbia University, New York City. Dec., 1924.
CONDIT, D. DALE, c/o Whitehall Petroleum Corp., Ltd., Bamboo Villa, Shillong, Assam, India. Dec., 1916.
CONDRA, GEORGE E., University of Nebraska, Lincoln, Neb. Dec., 1926.
COOK, CHARLES W., University of Michigan, Ann Arbor, Mich. Dec., 1915.
COOKE, C. WYTHE, U. S. Geological Survey, Washington, D. C. Dec., 1918.
CORBETT, CLIFTON S., c/o Nederlandsche Petroleum Maatschappij, Batavia, Java. Dec., 1925.
COSTE, EUGENE, 410 Royal Bank Bldg., Toronto, Canada. Dec., 1906.
COTTON, LEO ARTHUR, University of Sydney, Sydney, Australia. Dec., 1924.
CRAWFORD, RALPH DIXON, 1050 Tenth St., Boulder, Colo. Dec., 1916.
CROOK, ALJA R., State Museum of Natural History, Springfield, Ill. Dec., 1898.
CROSS, WHITMAN, 101 East Kirke St., Chevy Chase, Md. May, 1889.
CULVER, GARRY E., 310 Center Ave., Stevens Point, Wis. Dec., 1891.
CULVER, HAROLD E., State College, Pullman, Wash. Dec., 1925.
CUMINGS, EDGAR R., Indiana University, Bloomington, Ind. August, 1901.
CUSHMAN, J. A., Sharon, Mass. Dec., 1919.
DAKE, C. L., Missouri School of Mines, Rolla, Mo. Dec., 1920.
DALE, N. C., Hamilton College, Clinton, N. Y. Dec., 1920.
DALY, REGINALD A., Harvard University, Cambridge, Mass. Dec., 1905.
DANA, EDWARD SALISBURY, Yale University, New Haven, Conn. Dec., 1908.
*DARTON, NELSON H., U. S. Geological Survey, Washington, D. C.
DAVIS, E. F., 417 E. Randolph St., Glendale, Calif. Dec., 1920.
*DAVIS, WILLIAM M., 31 Hawthorne St., Cambridge, Mass.
DAY, ARTHUR LOUIS, Geophysical Laboratory, Washington, D. C. Dec., 1909.
DEAN, BASHFORD, Riverdale-on-Hudson, New York, N. Y. Dec., 1910.
DECKER, CHARLES ELIJAH, University of Oklahoma, Norman, Okla. Dec., 1924.
DE GOLYER, E. L., 65 Broadway, New York City. Dec., 1918.
DEUSSEN, ALEXANDER, 1917 Post-Dispatch Bldg., Houston, Texas. Dec., 1916.
DE WOLF, FRANK WILBRIDGE, 3502 Audubon Place, Houston, Texas. Dec., 1909.
DICKERSON, ROY E., P. O. Box 127, Belmont, Calif. Dec., 1918.
*DILLER, JOSEPH S., U. S. Geological Survey, Washington, D. C.
D'INVILLIERS, EDWARD V., 121 North Broad St., Philadelphia, Pa. Dec., 1888.
DODGE, RICHARD E., Storrs, Conn. August, 1897.
DOLMAGE, VICTOR, 510 Pacific Bldg., Vancouver, B. C. Dec., 1922.
DRAKE, NOAH FIELDS, Fayetteville, Ark. Dec., 1898.
DRESSER, JOHN A., 701 Eastern Townships Bank Bldg., Montreal, Canada. Dec., 1906.
DUNBAR, C. O., Yale University, New Haven, Conn. Dec., 1920.
EAKLE, ARTHUR S., University of California, Berkeley, Calif. Dec., 1899.
ECKEL, EDWIN C., 1503 Decatur St. N. W., Washington, D. C. Dec., 1905.
EMERY, WILSON B., Casper, Wyoming. Dec., 1919.

*Emerson, Benjamin K., Amherst, Mass.
Emmons, William H., Univ. of Minnesota, Minneapolis, Minn. Dec., 1912.
*Fairchild, Herman L., University of Rochester, Rochester, N. Y.
Farrington, Oliver C., Field Museum of Natural History, Chicago, Ill. Dec., 1895.
Fath, A. E., Chrisman, Ill. Dec., 1920.
Fenneman, Nevin M., University of Cincinnati, Cincinnati, Ohio. Dec., 1904.
Fenner, Clarence N., Geophysical Laboratory, Washington, D. C. Dec., 1911.
Ferguson, H. G., U. S. Geological Survey, Washington, D. C. Dec., 1920.
Fettke, Charles R., Carnegie Institute of Technology, Pittsburgh, Pa. Dec., 1924.
Field, Richard M., Princeton University, Princeton, N. J. Dec., 1926.
Fisher, Cassius Asa, 711 First Nat'l Bank Bldg., Denver, Colo. Dec., 1908.
Foerste, August F., 129 Wroe Ave., Dayton, Ohio. Dec., 1899.
Fohs, Ferdinand Julius, 51 East 42d St., New York, N. Y. Dec., 1923.
Ford, William E., Sheffield Scientific School, New Haven, Conn. Dec., 1915.
Foye, W. G., Wesleyan University, Middletown, Conn. Dec., 1919.
Fuller, Myron L., 60 Main St., Brockton, Mass. Dec., 1898.
Gale, Hoyt Stoddard, 1775 Hill Drive, Eagle Rock, Los Angeles, Calif. Dec., 1926.
Galloway, J. J., Columbia University, New York, N. Y. Dec., 1920.
Galpin, Sidney L., West Virginia University, Morgantown, W. Va. Dec., 1917.
Gane, Henry Stewart, Rural Del. No. 1, Santa Barbara, Calif. Dec., 1896.
Gardner, James H., 626 Kennedy Bldg., Tulsa, Okla. Dec., 1911.
Gardner, Julia A., U. S. Geological Survey, Washington, D. C. Dec., 1920.
George, Russell D., University of Colorado, Boulder, Colo. Dec., 1906.
Gidley, James William, U. S. Nat'l Museum, Washington, D. C. Dec., 1922.
Giles, Albert W., University of Arkansas, Fayetteville, Ark. Dec., 1921.
Gill, Adam Capen, Cornell University, Ithaca, N. Y. Dec., 1888.
Gilmore, Charles Whitney, U. S. National Museum, Washington, D. C. Dec., 1924.
Glenn, L. C., 2111 Garland Ave., Nashville, Tenn. June, 1900.
Goldman, Marcus I., U. S. Geol. Survey, Washington, D. C. Dec., 1916.
Goldring, Winifred, New York State Museum, Albany, N. Y. Dec., 1921.
Goldthwait, James Walter, Dartmouth College, Hanover, N. H. Dec., 1900.
Gordon, Charles H., University Library, University of Tennessee, Knoxville, Tenn. August, 1893.
Gordon, Clarence E., Massachusetts Agricultural College, Amherst, Mass. Dec., 1913.
Gould, Charles N., 215 S. Webster, Norman, Okla. Dec., 1904.
Grabau, Amadeus W., Government University, Peking, China. Dec., 1898.
Granger, Walter, American Museum of Natural History, New York, N. Y. Dec., 1911.
Grant, Ulysses Sherman, Northwestern Univ., Evanston, Ill. Dec., 1890.
Grasty, John Sharshall, Box 458, Charlottesville, Va. Dec., 1911.
Graton, Louis C., Rotch Building, Cambridge, Mass. Dec., 1913.
Gregory, Herbert E., Yale University, New Haven, Conn. August, 1901.
Greene, Frank Cook, 1434 S. Cincinnati Ave., Tulsa, Okla. Dec., 1917.
Grimsley, George P., 16 York Court, Baltimore, Md. August, 1895.

GROUT, FRANK F., University of Minnesota, Minneapolis, Minn. Dec., 1918.
GRUNER, JOHN W., University of Minnesota, Minneapolis, Minn. Dec., 1923.
GUNTER, HERMAN, State Geological Survey, Tallahassee, Fla. Dec., 1926.
*GURLEY, WILLIAM F. E. R., 6151 University Ave., Chicago, Ill.
HALBERSTADT, BAIRD, Pottsville, Pa. Dec., 1909.
HALL, GEORGE M., University of Tennessee, Knoxville, Tenn. Dec., 1926.
HANCE, J. H., Agricultural and Mechanical College, College Station, Texas. Dec., 1920.
HANCOCK, E. T., Romano-Americana, Ploesti, Rumania. Dec., 1919.
HARDER, E. C., 1111 Harrison Bldg., Philadelphia, Pa. Dec., 1918.
HARES, C. J., 305 Franklin St., Denver, Colo. Dec., 1920.
HARRIS, GILBERT D., Cornell University, Ithaca, N. Y. Dec., 1903.
HARTNAGEL, CHRIS A., New York State Museum, Albany, N. Y. Dec., 1913.
HASTINGS, JOHN B., 8663 Cypress Ave., Southgate, Calif. May, 1889.
*HAWORTH, ERASMUS, University of Kansas, Lawrence, Kans.
HAY, OLIVER P., Carnegie Institution, Washington, D. C. Dec., 1921.
HAYES, ALBERT O., Rutgers University, New Brunswick, N. J. Dec., 1919.
HAYNES, WINTHROP PERRIN, 82 Avenue des Champs Elysees, Paris, France. Dec., 1926.
HEALD, K. C., 1161 Frick Bldg. Annex, Pittsburgh, Pa. Dec., 1920.
HENDERSON, JUNIUS, University of Colorado, Boulder, Colo. Dec., 1925.
HENNEN, RAY V., Transcontinental Oil Co., Tulsa, Okla. Dec., 1914.
HERSHEY, OSCAR H., Crocker Bldg., San Francisco, Calif. Dec., 1909.
HESS, FRANK L., U. S. Geological Survey, Washington, D. C. Dec., 1921.
HEWETT, DONNEL F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
HIGGINS, DANIEL F., 747 N. Jefferson Ave., Loveland, Colo. Dec., 1925.
HILL, J. M., 2671 Shasta Road, Berkeley, Calif. Dec., 1920.
*HILL, ROBERT T., Los Angeles Museum of Science & Arts, Los Angeles, Calif.
HILLS, THOMAS MCDOUGALL, Vassar College, Poughkeepsie, N. Y. Dec., 1924.
HINDS, HENRY, 1153 Laurel Ave., St. Paul, Minn. Dec., 1912.
HINTZE, FERDINAND FRIIS, 580 Corona St., Denver, Colo. Dec., 1917.
HOBBS, WILLIAM H., University of Michigan, Ann Arbor, Mich. August, 1891.
HOLDEN, ROY J., Virginia Polytechnic Institute, Blacksburg, Va. Dec., 1914.
HOLLAND, WILLIAM JACOB, Carnegie Museum, Pittsburgh, Pa. Dec., 1910.
HOLLICK, ARTHUR, N. Y. Botanical Garden, New York, N. Y. August, 1898.
HOPKINS, O. B., Internat. Petr. Co., Ltd., 56 Church St., Toronto, Canada. Dec., 1919.
HOPKINS, THOMAS C., Syracuse University, Syracuse, N. Y. Dec., 1894.
HOTCHKISS, WILLIAM OTIS, College of Mines, Houghton, Mich. Dec., 1911.
HOWE, ERNEST, Litchfield, Conn. Dec., 1903.
HOWELL, BENJAMIN F., Princeton University, Princeton, N. J. Dec., 1926.
HUBBARD, GEORGE D., Oberlin College, Oberlin, Ohio. Dec., 1914.
HUDSON, GEORGE H., 39 Broad Street, Plattsburg, N. Y. Dec., 1917.
HUME, GEORGE S., Geological Survey of Canada, Ottawa, Canada. Dec., 1923.
HUNT, WALTER F., University of Michigan, Ann Arbor, Mich. Dec., 1914.
HUNTINGTON, ELLSWORTH, Yale University, New Haven, Conn. Dec., 1906.
HUSSAKOF, LOUIS, 1537 50th St., Brooklyn, N. Y. Dec., 1910.
HYDE, J. E., Western Reserve University, Cleveland, Ohio. Dec., 1916.
JACKSON, ROBERT T., Peterborough, N. H. August, 1894.

JACOBS, ELBRIDGE C., University of Vermont, Burlington, Vt. Dec., 1921.
JEFFERSON, MARK S. W., Michigan State Normal College, Ypsilanti, Mich. Dec., 1904.
JEFFREY, EDWARD C., Harvard University, Cambridge, Mass. Dec., 1914.
JENKINS, OLAF P., Nederlandsche Koloniale Petroleum Maatschappy, Sluisburg, Weltevreden, Batavia, Java. Dec., 1921.
JOHANNSEN, ALBERT, University of Chicago, Chicago, Ill. Dec., 1908.
JOHNSON, B. L., U. S. Bureau of Mines, Washington, D. C. Dec., 1919.
JOHNSON, DOUGLAS WILSON, Columbia University, New York, N. Y. Dec., 1906.
JOHNSON, ROSWELL H., University of Pittsburgh, Pittsburgh, Pa. Dec., 1918.
JONAS, ANNA I., Room 4230, U. S. Geological Survey, Washington, D. C. Dec., 1922.
KATZ, FRANK JAMES, U. S. Geological Survey, Washington, D. C. Dec., 1912.
KAY, GEORGE FREDERICK, State Univ. of Iowa, Iowa City, Iowa. Dec., 1908.
KEITH, ARTHUR, U. S. Geological Survey, Washington, D. C. May, 1889.
KEW, W. S. W., 1215 N. Howard St., Glendale, Calif. Dec., 1920.
KEYES, CHARLES ROLLIN, 944 Fifth St., Des Moines, Iowa. August, 1890.
KINDLE, EDWARD M., Victoria Memorial Museum, Ottawa, Canada. Dec., 1905.
KIRK, CHARLES T., Box 1592, Tulsa, Okla. Dec., 1915.
KIRK, EDWIN, U. S. Geological Survey, Washington, D. C. Dec., 1912.
KNAPPEN, RUSSELL S., Gulf Refining Co., Frick Bldg. Annex, Pittsburgh, Pa. Dec., 1926.
KNIGHT, CYRIL WORKMAN, Nipissing Mining Co., Ltd., Cobalt, Ontario, Canada. Dec., 1911.
KNOPF, ADOLPH, Yale Station New Haven, Conn. Dec., 1911.
KNOPF, ELEANORA BLISS, 105 East Rock Road, New Haven, Conn. Dec., 1919.
KRAUS, EDWARD HENRY, Univ. of Michigan, Ann Arbor, Mich. June, 1902.
KUMMEL, HENRY B., Trenton, N. J. Dec., 1895.
*KUNZ, GEORGE F., 401 Fifth Ave., New York, N. Y.
LAHEE, FREDERIC H., American Exchange Natl. Bank Bldg., Dallas, Texas. Dec., 1917.
LANDES, HENRY, University of Washington, University Station, Seattle, Wash. Dec., 1908.
LANE, ALFRED C., Tufts College, Mass. Dec., 1889.
LARSEN, ESPER S., JR., Geol. Mus., Harvard Univ., Cambridge, Mass. Dec., 1914.
LAWSON, ANDREW C., University of California, Berkeley, Calif. May, 1889.
LEES, JAMES H., Iowa Geological Survey, Des Moines, Iowa. Dec., 1914.
LEIGHTON, MORRIS M., Illinois Geological Survey, Urbana, Ill. Dec., 1921.
LEITH, CHARLES K., University of Wisconsin, Madison, Wis. Dec., 1902.
LEONARD, ARTHUR G., State University of North Dakota, Grand Forks, N. Dak. Dec., 1901.
LEVERETT, FRANK, Ann Arbor, Mich. August, 1890.
LEWIS, JOSEPH VOLNEY, Rutgers University, New Brunswick, N. J. Dec., 1906.
LIBBEY, WILLIAM, Princeton University, Princeton, N. J. August, 1899.
LIDDLE, RALPH ALEXANDER, The Pure Oil Co., Mexia, Texas. Dec., 1921.
LINDGREN, WALDEMAR, Massachusetts Institute of Technology, Cambridge, Mass. August, 1890.

LISBOA, MIGUEL A. R., Caixa postal 829, Ave. Rio Branco 46-V, Rio de Janeiro, Brazil. Dec., 1913.
LITTLE, HOMER P., Clark University, Worcester, Mass. Dec., 1918.
LLOYD, E. R., First National Bank Bldg., Denver, Colo. Dec., 1919.
LOBECK, ARMIN KOHL, University of Wisconsin, Madison, Wis. Dec., 1924.
LOGAN, WILLIAM N., Indiana University, Bloomington, Ind. Dec., 1917.
LONGWELL, CHESTER R., Yale University, New Haven, Conn. Dec., 1923.
LOOMIS, FREDERICK BREWSTER, Amherst College, Amherst, Mass. Dec., 1909.
LOUDERBACK, GEORGE D., University of California, Berkeley, Calif. June, 1902.
LOUGHLIN, GERALD F., U. S. Geological Survey, Washington, D. C. Dec., 1916.
LOW, ALBERT P., 154 McLaren St., Ottawa, Canada. Dec., 1905.
LULL, RICHARD SWANN, Yale University, New Haven, Conn. Dec., 1909.
LUPTON, CHARLES T., 611 17th St., Denver, Colo. Dec., 1916.
MCCALLIE, SAMUEL WASHINGTON, Atlanta, Ga. Dec., 1909.
MCCASKEY, HIRAM D., Central Point, Oregon. Dec., 1904.
MCCONNELL, RICHARD G., Rideau Club, Ottawa, Canada. May, 1889.
MCCOY, ALEX. W., P. O. Box 1169, Denver, Colo. Dec., 1922.
MACDONALD, DONALD F., 16 Eastover Court, Louisville, Ky. Dec., 1915.
MACFARLANE, JAMES RIEMAN, Woodland Road, Pittsburgh, Pa. August, 1891.
MACKAY, BERTRAM R., Geological Survey, Ottawa, Canada. Dec., 1922.
MCKELLAR, PETER, Fort William, Ontario, Canada. August, 1890.
MCLAUGHLIN, DONALD H., Rotch Bldg., Harvard University, Cambridge, Mass. Dec., 1922.
MCLEARN, FRANK HARRIS, Geological Survey, Ottawa, Canada. Dec., 1923.
MALOTT, CLYDE A., Indiana University, Bloomington, Ind. Dec., 1926.
MANSFIELD, GEORGE R., 2067 Park Rd. N. W., Washington, D. C. Dec., 1909.
MARBUT, CURTIS F., Bureau of Soils, Washington, D. C. August, 1897.
MARSTERS, VERNON F., 3501 Smart Ave., Kansas City, Mo. Aug., 1892.
MARTIN, GEORGE C., 3126 38th Street, Washington, D. C. June, 1902.
MARTIN, LAWRENCE, Library of Congress, Washington, D. C. Dec., 1909.
MATHER, KIRTLEY F., Harvard Geological Museum, Cambridge, Mass., Dec., 1918.
MATHEWS, EDWARD B., Johns Hopkins University, Baltimore, Md. Aug., 1895.
MATSON, GEORGE C., 408 Cosden Bldg., Tulsa, Okla. Dec., 1918.
MATTHES, FRANCOIS E., U. S. Geol. Survey, Washington, D. C. Dec., 1914.
MATTHEW, W. D., American Museum of Natural History, New York, N. Y. Dec., 1903.
MAURY, CARLOTTA J., 50-A Locust Hill Ave., Yonkers, N. Y. Dec., 1920.
MAYNARD, THOMAS POOLE, 181 Myrtle St., Atlanta, Ga. Dec., 1914.
MEAD, WARREN JUDSON, University of Wisconsin, Madison, Wis. Dec., 1916.
MEHL, MAURICE G., University of Missouri, Columbia, Mo. Dec., 1922.
MEINZER, OSCAR E., U. S. Geological Survey, Washington, D. C. Dec., 1916.
MENDENHALL, WALTER C., U. S. Geol. Survey, Washington, D. C. June, 1902.
MERRIAM, JOHN C., Carnegie Institution, Washington, D. C. August, 1895.
MERRILL, GEORGE P., U. S. National Museum, Washington, D. C. Dec., 1888.
MERTIE, JOHN BEAVER, JR., 112 Park Ave., Takoma Park, D. C. Dec., 1923.
MERWIN, HERBERT E., Geophysical Laboratory, Washington, D. C. Dec., 1914.
MILLER, ARTHUR M., State University of Kentucky, Lexington, Ky. Dec., 1897.
MILLER, BENJAMIN L., Lehigh University, Bethlehem, Pa. Dec., 1904.

MILLER, WILLIAM JOHN, University of California, Southern Branch, Los Angeles, Calif. Dec., 1909.
MISER, HUGH D., U. S. Geological Survey, Washington, D. C. Dec., 1916.
MOFFIT, FRED HOWARD, U. S. Geological Survey, Washington, D. C. Dec., 1912.
MONNETT, VICTOR E., University of Oklahoma, Norman, Okla. Dec., 1926.
MOORE, ELWOOD S., University of Toronto, Toronto, Canada. Dec., 1911.
MOORE, RAYMOND C., University of Kansas, Lawrence, Kans. Dec., 1921.
MOOK, CHARLES C., Metuchen, N. J. Dec., 1922.
MORSE, WILLIAM C., Massachusetts Institute of Technology, Cambridge, Mass. Dec., 1925.
MUNN, MALCOLM JOHN, 305 Cosden Bldg., Tulsa, Okla. Dec., 1909.
*NASON, FRANK L., West Haven, Conn.
NELSON, W. A., University, Va. Dec., 1920.
NEWLAND, DAVID HALE, Albany, N. Y. Dec., 1906.
NEWSOM, JOHN F., Hobart Bldg., San Francisco, Calif. Dec., 1899.
NOBLE, LEVI F., Valyermo, Calif. Dec., 1916.
NORTON, WILLIAM H., Cornell College, Mount Vernon, Iowa. Dec., 1895.
O'CONNELL, MARJORIE, 116-57 Farmers Blvd., St. Albans, L. I. Dec., 1919.
OGILVIE, IDA HELEN, Barnard College, Columbia University, New York, N. Y. Dec., 1906.
O'HARRA, CLEOPHAS C., South Dakota School of Mines, Rapid City, S. Dak. Dec., 1904.
OHERN, DANIEL WEBSTER, 515 W. 14th St., Oklahoma City, Okla. Dec., 1911.
O'NEILL, J. J., McGill University, Montreal, Canada. Dec., 1920.
OSBORN, HENRY F., American Museum of Natural History, New York, N. Y. August, 1894.
OVERBECK, ROBERT M., c/o Caracoles Tin Co. of Bolivia, Casilla No. 674, La Paz, Bolivia, South America. Dec., 1921.
PACK, FREDERICK J., University of Utah, Salt Lake City, Utah. Dec., 1926.
PACK, ROBERT W., Box 790, Beaumont, Texas. Dec., 1916.
PAIGE, SIDNEY, U. S. Geological Survey, Washington, D. C. Dec., 1911.
PALACHE, CHARLES, Harvard University, Cambridge, Mass. August, 1897.
PARKS, WILLIAM A., University of Toronto, Toronto, Canada. Dec., 1906.
*PATTON, HORACE B., 3111 West 36th Ave., Denver, Colo.
PENROSE, RICHARD A. F., JR., Bullitt Bldg., Philadelphia, Pa. May, 1889.
PERKINS, GEORGE H., University of Vermont, Burlington, Vt. June, 1902.
PERRY, JOSEPH H., 276 Highland St., Worcester, Mass. Dec., 1888.
PHALEN, WILLIAM C., Drawers 1 and 2, Syracuse, N. Y. Dec., 1912.
PHILLIPS, ALEXANDER H., Princeton University, Princeton, N. J. Dec., 1914.
PLUMMER, FREDERICK B., 3100 Wabash Ave., Fort Worth, Texas. Dec., 1925.
POGUE, JOSEPH E., 42 West 12th St., New York City. Dec., 1911.
POWERS, SIDNEY, Amerada Petr. Corp., Tulsa, Okla. Dec., 1920.
PRATT, JOSEPH H., North Carolina Geol. Survey, Chapel Hill, N. C. Dec., 1898.
PRATT, W. E., Humble Oil and Refining Co., Houston, Texas. Dec., 1920.
PRICE, W. ARMSTRONG, 1312 Niels Esperson Bldg., Houston, Texas. Dec., 1916.
PRINDLE, LOUIS M., U. S. Geological Survey, Washington, D. C. Dec., 1912.
PROUTY, WILLIAM F., Univ. of North Carolina, Chapel Hill, N. C. Dec., 1911.
QUIRKE, TERENCE T., University of Illinois, Urbana, Ill. Dec., 1921.
RANSOME, FREDERICK L., University Station, Tucson, Ariz. August, 1895.

RAYMOND, PERCY EDWARD, Museum of Comparative Zoology, Cambridge, Mass. Dec., 1907.

REBER, LOUIS E., Box 1096, Jerome, Ariz. Dec., 1923.

REEDS, CHESTER A., American Museum of Natural History, New York, N. Y. Dec., 1913.

REESIDE, JOHN B., JR., U. S. Geological Survey, Hyattsville, Md. Dec., 1921.

REEVES, FRANK, U. S. Geological Survey, Washington, D. C. Dec., 1924.

REGER, DAVID B., Box 816, Morgantown, W. Va. Dec., 1918.

REID, HARRY FIELDING, Johns Hopkins University, Baltimore, Md. Dec., 1892.

REINECKE, LEOPOLD, P. O. Box 2682, Johannesburg, Transvaal, South Africa. Dec., 1916.

RENICK, B. COLEMAN, Roxana Petr. Corp., Athletic Assoc. Bldg., Dallas, Texas. Dec., 1926.

RESSER, CHARLES E., U. S. National Museum, Washington, D. C. Dec., 1926.

RICE, WILLIAM NORTH, Wesleyan University, Middletown, Conn. Aug., 1890.

RICH, JOHN LYON, Box 3, Ottawa, Kans. Dec., 1912.

RICHARDS, R. W., U. S. Geological Survey, Washington, D. C. Dec., 1920.

RICHARDSON, CHARLES H., Syracuse University, Syracuse, N. Y. Dec., 1899.

RICHARDSON, GEORGE B., U. S. Geol. Survey, Washington, D. C. Dec., 1908.

RICHARZ, STEPHEN, St. Mary's College, Techny, Ill. Dec., 1926.

RIES, HEINRICH, Cornell University, Ithaca, N. Y. Dec., 1893.

RIGGS, ELMER S., Field Museum of Natural History, Chicago, Ill. Dec., 1911.

ROBERTS, JOSEPH K., University of Virginia, Charlottesville, Va. Dec., 1926.

RODDY, H. J., State Normal School, Millersville, Pa. Dec., 1919.

ROGERS, AUSTIN F., Stanford University, Calif. Dec., 1918.

ROSE, BRUCE, Department of Geology, Queens University, Kingston, Ontario, Canada. Dec., 1916.

ROSS, CLARENCE, U. S. Geological Survey, Washington, D. C. Dec., 1926.

RUEDEMANN, RUDOLF, New York State Museum, Albany, N. Y. Dec., 1905.

RUTLEDGE, JOHN JOSEPH, State Bureau of Mines, 22 Light St., Baltimore, Md. Dec., 1911.

SALES, RENO H., Anaconda Copper Mining Co., Butte, Mont. Dec., 1916.

SAMPSON, EDWARD, Princeton University, Princeton, N. J. Dec., 1924.

SARDESON, FREDERICK W., 414 Harvard St., S. E. Minneapolis, Minn. Dec., 1892.

SAYLES, ROBERT WILCOX, Harvard University, Chestnut Hill, Mass. Dec., 1917.

SAVAGE, THOMAS EDMUND, University of Illinois, Urbana, Ill. Dec., 1907.

SCHALLER, WALDEMAR T., U. S. Geol. Survey, Washington, D. C. Dec., 1918.

SCHOFIELD, S. J., University of British Columbia, Vancouver, B. C. Dec., 1918.

SCHRADER, FRANK C., U. S. Geological Survey, Washington, D. C. Aug., 1901.

SCHUCHERT, CHARLES, Yale University, New Haven, Conn. August, 1895.

SCHULTZ, ALFRED R., 800 Vine Street, Hudson, Wis. Dec., 1912.

SCHWARTZ, GEORGE M., Univ. of Minnesota, Minneapolis, Minn. Dec., 1923.

SCOTT, IRVING D., University of Michigan, Ann Arbor, Mich. Dec., 1923.

SCOTT, WILLIAM B., Princeton University, Princeton, N. J. August, 1892.

SEAMAN, ARTHUR E., Michigan College of Mines, Houghton, Mich. Dec., 1904.

SEARS, JULIAN DUCKER, 209 E. Underwood St., Chevy Chase, Md. Dec., 1924.

SELLARDS, ELIAS H., University of Texas, Austin, Texas. Dec., 1905.

SEMMES, DOUGLAS R., Box 265, Cisco, Texas. Dec., 1921.

SHALER, MILLARD K., 66 Rue Des Colonies, Brussels, Belgium. Dec., 1914.
SHATTUCK, GEORGE BURBANK, Mt. Royal Station, Baltimore, Md. Aug., 1899.
SHAW, EUGENE W., Room 1560, 81 New Street, New York, N. Y. Dec., 1912.
SHEDD, SOLON, Box 1888, Stanford University, Calif. Dec., 1904.
SHEPARD, EDWARD M., 1403 Benton Ave., Springfield, Mo. August, 1901.
SHIMEK, BOHUMIL, University of Iowa, Iowa City, Iowa. Dec., 1904.
SHIMER, HERVEY WOODBURN, Massachusetts Institute of Technology, Cambridge, Mass. Dec., 1910.
SHULER, E. W., South Methodist University, Dallas, Texas. Dec., 1920.
SIEBENTHAL, CLAUDE E., U. S. Geol. Survey, Washington, D. C. Dec., 1912.
*SIMONDS, FREDERICK W., University of Texas, Austin, Texas.
SIMPSON, HOWARD E., University of North Dakota, Grand Forks, N. Dak. Dec., 1923.
SINCLAIR, WILLIAM JOHN, Princeton University, Princeton, N. J. Dec., 1906.
SINGEWALD, JOSEPH T., Jr., Johns Hopkins University, Baltimore, Md. Dec., 1911.
SLOAN, EARLE, Charleston, S. C. Dec., 1908.
SMITH, BURNETT, Syracuse University, Skaneateles, N. Y. Dec., 1911.
SMITH, CARL, Agra, Okla. Dec., 1912.
*SMITH, EUGENE A., University of Alabama, University, Ala.
SMITH, GEORGE OTIS, U. S. Geological Survey, Washington, D. C. Aug., 1897.
SMITH, PHILIP S., U. S. Geological Survey, Washington, D. C. Dec., 1909.
SMITH, RICHARD A., Biological Survey of Michigan, Lansing, Mich. Dec., 1921.
SMITH, STANLEY, University of Bristol, Bristol, England. Dec., 1922.
SMITH, WARREN DU PRÉ, University of Oregon, Eugene, Ore. Dec., 1909.
SMITH, W. S. TANGIER, 640 Tennyson Ave., Palo Alto, Calif. June, 1902.
SMYTH, CHARLES H., JR., Princeton University, Princeton, N. J. Aug., 1892.
SMYTH, HENRY L., Harvard University, Cambridge, Mass. August, 1894.
SOMERS, R. E., Oil and Gas Bldg., University of Pittsburgh, Pittsburgh, Pa. Dec., 1919.
SOPER, EDGAR K., 845 Muirfield Road, Los Angeles, California. Dec., 1918.
SOSMAN, R. B., Geophysical Laboratory, Washington, D. C. Dec., 1920.
SPEIGHT, ROBERT, Canterbury College, Christ Church, New Zealand. Dec., 1916.
SPENCER, ARTHUR COE, U. S. Geological Survey, Washington, D. C. Dec., 1896.
SPIEKER, EDMUND MAUTE, State University of Ohio, Columbus, Ohio. Dec., 1924.
SPRINGER, FRANK, U. S. National Museum, Washington, D. C. Dec., 1911.
SPURR, JOSIAH E., c/o Engineering and Mining Journal, 10th Ave. and 36th St., New York, N. Y. Dec., 1894.
STANLEY-BROWN, JOSEPH, 44 Wall Street, New York, N. Y. August, 1892.
STANTON, TIMOTHY W., U. S. Nat'l Museum, Washington, D. C. August, 1891.
STAUFFER, CLINTON R., Univ. of Minnesota, Minneapolis, Minn. Dec., 1911.
STEBINGER, EUGENE, JR., 719 Edificio Banco Boston, Buenos Aires, Argentina. Dec., 1916.
STEIDTMANN, EDWARD, 13 White St., Lexington, Va. Dec., 1916.
STEPHENSON, LLOYD W., U. S. Geol. Survey, Washington, D. C. Dec., 1911.
STOLLER, JAMES HOUGH, Union College, Schenectady, N. Y. Dec., 1917.
STONE, RALPH WALTER, State Geological Survey, Harrisburg, Pa. Dec., 1912.
STOSE, GEORGE WILLIS, U. S. Geological Survey, Washington, D. C. Dec., 1908.

STOUT, WILBER, Geological Survey of Ohio, Columbus, Ohio. Dec., 1918.
SUSSMILCH, CARL ADOLPH, Technical College, Newcastle, Australia. Dec., 1925.
SWARTZ, CHARLES K., Johns Hopkins University, Baltimore, Md. Dec., 1908.
TABER, STEPHEN, University of South Carolina, Columbia, S. C. Dec., 1914.
TAFF, JOSEPH A., 629 Cooper St., Palo Alto, Calif. August, 1895.
TALBOT, MIGNON, Mount Holyoke College, South Hadley, Mass. Dec., 1913.
TALMAGE, JAMES E., Durham House, Edge Lane, Liverpool, England. Dec., 1897.
TARR, WILLIAM ARTHUR, 704 Westwood Ave., Columbia, Mo. Dec., 1917.
TAYLOR, FRANK B., 420 Downing Ave., Fort Wayne, Ind. Dec., 1895.
THIEL, GEORGE A., University of Minnesota, Minneapolis, Minn. Dec., 1925.
THOM, WILLIAM TAYLOR, JR., U. S. Geological Survey, Washington, D. C. Dec., 1924.
THOMAS, ABRAM O., University of Iowa, Iowa City, Iowa. Dec., 1921.
THORPE, MALCOLM R., 1463 Yale Station, New Haven, Conn. Dec., 1923.
THWAITES, FREDRIK T., Science Hall, Madison, Wis. Dec., 1925.
TILTON, J. L., Morgantown, W. Va. Dec., 1920.
TOMLINSON, CHARLES WELDON, 1610 Bixby Ave., Ardmore, Okla. Dec., 1917.
TROWBRIDGE, ARTHUR C., State Univ. of Iowa, Iowa City, Iowa. Dec., 1913.
TROXELL, EDWARD L., Trinity College, Hartford, Conn. Dec., 1923.
*TURNER, HENRY W., Mills Bldg., San Francisco, Calif.
TWENHOFEL, WILLIAM H., University of Wisconsin, Madison, Wis. Dec., 1913.
TYRRELL, JOSEPH B., 810 Lumsden Bldg., Toronto 2, Canada. May, 1889.
UDDEN, JOHAN A., University of Texas, Austin, Texas. August, 1897. 1922.
ULRICH, EDWARD O., U. S. Geological Survey, Washington, D. C. Dec., 1903.
UMPLEBY, JOSEPH B., University of Oklahoma, Norman, Okla. Dec., 1913.
*UPHAM, WARREN, Minnesota Historical Society, Saint Paul, Minn.
VAN HORN, F. R., Case School of Applied Science, Cleveland, Ohio. Dec., 1898.
VAN TUYL, FRANCIS M., Colorado School of Mines, Golden, Colo. Dec., 1917.
VAUGHAN, T. WAYLAND, Scripps Institution, La Jolla, Calif. August, 1896.
VEATCH, ARTHUR CLIFFORD, 7 Central Drive, Port Washington, N. Y. Dec., 1906.
VISHER, STEPHEN S., 817 E. Second St., Bloomington, Ind. Dec., 1923.
WADE, BRUCE, State Geological Survey, Nashville, Tenn. Dec., 1920.
WALKER, THOMAS L., University of Toronto, Toronto, Canada. Dec., 1903.
WARD, FREEMAN, Lafayette College, Easton, Pa. Dec., 1925.
WARD, LEONARD KEITH, Department of Mines, Adelaide, South Australia. Dec., 1924.
WARING, GERALD A., Margay Oil Corp., Box 2103, Tulsa, Okla. Dec., 1921.
WARREN, CHARLES H., Yale University, New Haven, Conn. Dec., 1901.
WASHBURNE, C. W., 27 William St., New York, N. Y. Dec., 1919.
WASHINGTON, HENRY S., Geophysical Laboratory, Washington, D. C. Aug., 1896.
WEAVER, CHARLES E., University of Washington, Seattle, Wash. Dec., 1913.
WEED, WALTER H., Post Road, Scarsdale, N. Y. May, 1889.
WEGEMANN, CARROLL H., Pan American Exploration Co., 120 Broadway, New York, N. Y. Dec., 1912.

WEIDMAN, SAMUEL, 814 Monett St., Norman, Okla. Dec., 1903.
WELLER, STUART, University of Chicago, Chicago, Ill. June, 1900.
WELLS, ROGER C., U. S. Geological Survey, Washington, D. C. Dec., 1921.
WENTWORTH, CHESTER K., U. S. Geological Survey, Washington, D. C. Dec. 1923.
WESTGATE, LEWIS G., 124 Oak Hill Ave., Delaware, Ohio. August, 1894.
WHERRY, EDGAR T., Bureau of Chemistry, Washington, D. C. Dec., 1915.
WHITE, DAVID, U. S. National Museum, Washington, D. C. May, 1889.
*WHITE, ISRAEL C., Morgantown, W. Va.
WHITLOCK, H. P., Amer. Museum of Natural History, N. Y. City. Dec., 1920.
WHITNEY, FRANCIS L., University of Texas, Austin, Texas. Dec., 1923.
WIELAND, GEORGE REBER, Yale University, New Haven, Conn. Dec., 1910.
WILDER, FRANK A., North Holston, Smyth County, Va. Dec., 1905.
*WILLIAMS, EDWARD H., JR., Woodstock, Vt.
WILLIAMS, IRA A., 821 Spalding Bldg., Portland, Ore. Dec., 1905.
WILLIAMS, MERTON YARWOOD, Univ. of British Columbia, Vancouver, B. C. Dec., 1916.
WILLIS, BAILEY, Leland Stanford Jr. University, Stanford University, Calif. Dec., 1889.
WILSON, ALFRED W. G., Department of Mines, Ottawa, Canada. June, 1902.
WILSON, MORLEY EVANS, Geological Survey, Ottawa, Canada. Dec., 1916.
WINCHELL, ALEXANDER N., University of Wisconsin, Madison, Wis. Aug., 1901.
*WINSLOW, ARTHUR, 131 State St., Boston, Mass.
WOLFF, JOHN E., 360 S. Grand Ave., Pasadena, Calif. Dec., 1889.
WOOD, HARRY OSCAR, 200 N. San Rafael Ave., Pasadena, Calif. Dec., 1922.
WOODMAN, JOSEPH E., New York University, New York, N. Y. Dec., 1905.
WOODRING, WENDELL P., U. S. Geol. Survey, Washington, D. C. Dec., 1921.
WOODRUFF, E. G., 1611 S. Detroit St., Tulsa, Okla. Dec., 1922.
WOOLNOUGH, WALTER GEORGE, "Callabonna," Florence St., Killara, New South Wales. Dec., 1924.
WRATHER, WILLIAM E., 6044 Bryan Parkway, Dallas, Texas. Dec., 1923.
WRIGHT, CHARLES WILL, 28 Vie del Parliamento, Rome, Italy. Dec., 1900.
WRIGHT, FREDERIC E., Geophysical Laboratory, Washington, D. C. Dec., 1908.

CORRESPONDENTS DECEASED

CAPELLINI, GIOVANNI. Died 1924.
CREDNER, HERMAN. Died July 22, 1913.
DE STEFANI, CARLO. Died Dec. 12, 1924.
GEIKIE, SIR ARCHIBALD. Died Nov., 1924.
MICHEL-LÉVY, A. Died September, 1911.
KILIAN, W. Died 1926.
ROSENBUSCH, H. Died January 20, 1914.
SUESS, EDWARD. Died April 20, 1914.
TEALL, SIR J. J. H. Died July 2, 1924.
TSCHERNYSCHEW, TH. Died Jan. 15, 1914.
ZIRKEL, FERDINAND. Died June 11, 1912.

FELLOWS DECEASED

* Indicates Original Fellow (see article III of Constitution)

*ASHBURNER, CHAS. A. Died Dec. 24, 1889.
BARLOW, ALFRED E. Died May 28, 1914.
BARRELL, JOSEPH. Died May 4, 1919.
BEECHER, CHARLES E. Died Feb. 14, 1904.
*BECKER, GEORGE F. Died April 20, 1919.
BELL, ROBERT. Died June 18, 1917.
BICKMORE, ALBERT S. Died Aug. 12, 1914.
BLAKE, WM. PHIPPS. Died May 21, 1910.
BOWMAN, AMOS. Died June 18, 1894.
*BRANNER, JOHN C. Died March 1, 1922.
BROOKS, ALFRED H. Died Nov. 22, 1924.
BROWN, AMOS P. Died Oct. 9, 1917.
BUCKLEY, ERNEST R. Died Jan. 19, 1912.
CAIRNES, D. D. Died June 14, 1917.
*CALVIN, SAMUEL. Died April 17, 1911.
CARPENTER, FRANK R. Died April 1, 1910.
CASTILLO, ANTONIO DEL. Died Oct. 28, 1895.
CHAPIN, J. H. Died March 14, 1892.
CLARK, WILLIAM B. Died July 27, 1917.
CLARKE, JOHN MASON. Died May 29, 1925.
*CLAYPOLE, EDWARD W. Died Aug. 17, 1901.
*COMSTOCK, THEO. B. Died July 26, 1915.
COOK, GEORGE H. Died Sept. 22, 1889.
*COPE, EDWARD D. Died April 12, 1897.
COX, GEORGE H. Died August 20, 1922.
*CROSBY, WILLIAM O. Died Dec. 31, 1925.
*CUSHING, H. P. Died April 14, 1921.
*DANA, JAMES D. Died April 14, 1895.
DAVIS, CHARLES A. Died April 9, 1916.
DAWSON, GEORGE M. Died March 2, 1901.
DAWSON, SIR J. WM. Died Nov. 19, 1899.
DAY, DAVID T. Died April 15, 1925.
DERBY, ORVILLE A. Died Nov. 27, 1915.
DRYSDALE, CHAS. W. Died July 10, 1917.
*DUMBLE, EDWIN T. Died Jan. 26, 1927.
DUTTON, CLARENCE E. Died Jan. 4, 1912.
*DWIGHT, WM. B. Died Aug. 29, 1906.
EASTMAN, CHAS. R. Died Sept. 27, 1918.
*ELDRIDGE, GEORGE H. Died June 29, 1905.
*EMMONS, SAMUEL F. Died March 28, 1911.
FONTAINE, WM. M. Died April 30, 1913.
*FOOTE, ALBERT E. Died October 10, 1895.
*FRAZER, PERSIFOR. Died April 7, 1909.
*FULLER, HOMER T. Died Aug. 14, 1908.
*GILBERT, GROVE K. Died May 1, 1918.
GIROUX, N. J. Died Nov. 30, 1891.
HAGUE, ARNOLD. Died May 14, 1917.
*HALL, CHRISTOPHER W. Died May10, 1911.
*HALL, JAMES. Died August 7, 1898.
HARRISON, SIR J. B. Died Feb. 8, 1926.
HATCHER, JOHN B. Died July 3, 1904.
*HAY, ROBERT. Died December 14, 1895.
HAYES, C. WILLARD. Died Feb. 9, 1916.
*HEILPRIN, ANGELO. Died July 17, 1907.
HICE, RICHARD R. Died March 27, 1925.
HILGARD, EUGENE W. Died Jan. 8, 1916.
HILL, FRANK A. Died July 13, 1915.
HILLS, RICHARD C. Died Aug. 14, 1923.
*HITCHCOCK, CHAS. H. Died Nov. 7, 1919.
*HOLBROOK, LEVI. Died July 26, 1922.
*HOLMES, JOSEPH A. Died July 13, 1915.
*HONEYMAN, DAVID. Died Oct. 17, 1889.
*HOVEY, EDMUND O. Died Sept. 27, 1924.
*HOVEY, HORACE C. Died July 27, 1914.
*HOWELL, EDWIN E. Died April 16, 1911.
HUNT, THOMAS S. Died Feb. 12, 1892.
*HYATT, ALPHEUS. Died Jan. 15, 1902.
IDDINGS, J. P. Died Sept. 8, 1920.
IRVING, JOHN D. Died July 26, 1918.
JACKSON, THOMAS M. Died Feb. 3, 1912.
*JAMES, JOSEPH F. Died March 29, 1897.
JULIEN, ALEXIS A. Died May 7, 1919.
*KEMP, JAMES F. Died Nov. 17, 1926.
KENNEDY, WILLIAM. Died Feb. 23, 1926.
KNIGHT, WILBUR C. Died July 28, 1903.
KNOWLTON, FRANK H. Died Nov. 22, 1926.
LACOE, RALPH D. Died February 5, 1901.
LAFLAMME, J. C. K. Died July 6, 1910.
LAMBE, L. M. Died March 12, 1919.
LANGTON, DANIEL W. Died June 21, 1909.
*LE CONTE, JOSEPH. Died July 6, 1901.
LEE, WILLIS T. Died June 17, 1926.
*LESLEY, J. PETER. Died June 2, 1903.
LOUGHRIDGE, ROBT. H. Died July 1, 1917.
MCCALLEY, HENRY. Died Nov. 20, 1904.
*MCGEE, W J. Died Sept. 4, 1912.
MCINNES, WILLIAM. Died March 10, 1925.
MARCY, OLIVER. Died March 19, 1899.
MARSH, OTHNIEL C. Died March 18, 1899.
MELL, P. H. Died October 12, 1918.
*MERRILL, FRED. J. H. Died Nov. 29, 1916.
MILLER, WILLET G. Died Feb. 4, 1925.
MILLS, JAMES E. Died July 25, 1901.
*NASON, HENRY B. Died Jan. 17, 1895.

*Neff, Peter. Died May 11, 1903.
*Newberry, John S. Died Dec. 7, 1892.
Niles, William H. Died Sept. 12, 1910.
Norwood, Chas. J. Died Jan. 20, 1927.
*Orton, Edward. Died October 16, 1899.
*Osborn, Amos O. Died March, 1911.
*Owen, Richard. Died March 24, 1890.
Peck, Frederick B. Died Nov. 2, 1925.
Penfield, Samuel L. Died Aug. 14, 1906.
Penhallow, David P. Died Oct. 20, 1910.
Pirsson, L. V. Died Dec. 8, 1919.
*Platt, Franklin. Died July 24, 1900.
Pettee, William H. Died May 26, 1904.
*Powell, John W. Died Sept. 23, 1902.
*Prosser, Chas. S. Died Sept. 11, 1916.
*Pumpelly, Raphael. Died August, 1923.
Purdue, A. H. Died Dec. 12, 1917.
Robinson, Henry H. Died Oct. 20, 1925.
Rogers, G. S. Died Nov. 18, 1919.
*Russell, Israel C. Died May 1, 1906.
*Safford, James M. Died July 3, 1907.
Saint John, O. H. Died July 17, 1921.
*Salisbury, Rollin D. Died Aug. 15, 1922.
*Schaeffer, Charles. Died Nov. 23, 1903.
Seely, H. M. Died May 4, 1917.
Seña, J. C. da Costa. Died June 20, 1919.
*Shaler, Nathaniel S. Died Apr. 10, 1906.
*Smock, John C. Died April 21, 1926.
*Spencer, J. W. Died October 9, 1921.
*Stevenson, John J. Died Aug. 10, 1924.
Sutton, William J. Died May 9, 1915.
Tarr, Ralph S. Died March 21, 1912.
Tight, William G. Died Jan. 15, 1910.
*Todd, James E. Died October 29, 1922.
Twitchell, Mayville W. Died Apr., 1927.
Uglow, William L. Died Aug. 3, 1926.
*Van Hise, C. R. Died Nov. 19, 1918.
Van Ingen, Gilbert. Died July 7, 1925.
*Vogdes, Anthony W. Died Feb. 8, 1923.
Wachsmuth, Chas. Died Feb. 7, 1896.
Wadsworth, M. E. Died April 21, 1921.
*Walcott, Chas. D. Died Feb. 9, 1927.
Watson, Thomas L. Died Nov. 10, 1924.
Weston, Thomas C. Died July 20, 1910.
White, Theodore G. Died July 7, 1901.
*Whitfield, Robt. P. Died April 6, 1910.
*Williams, George H. Died July 12, 1894.
*Williams, J. Francis. Died Nov. 9, 1891.
*Williams, H. S. Died July 31, 1918.
Wilmott, Arthur B. Died May 8, 1914.
*Winchell, Alex. Died Feb. 19, 1891.
*Winchell, H. V. Died July 28, 1923.
*Winchell, Newton H. Died May 1, 1914.
Woodward, Robt. S. Died June 29, 1924.
Woodworth, Jay B. Died Aug. 4, 1925.
Wright, Albert A. Died April 2, 1905.
*Wright, G. F. Died April 20, 1921.
Yeates, William S. Died Feb. 19, 1908.

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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PROCEEDINGS OF THE TWENTY-FIFTH ANNUAL MEETING OF THE CORDILLERAN SECTION OF THE GEOLOGICAL SOCIETY OF AMERICA, HELD AT BERKELEY, CALIFORNIA, JANUARY 29 AND 30, 1926.

JOHN P. BUWALDA, *Secretary*

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Session of January 29

The Cordilleran Section of the Geological Society of America held its twenty-fifth annual meeting at the Department of Geology, Stanford University, California, on January 29 and 30, 1926, in conjunction with the Pacific Coast Branch of the Paleontological Society of America and the Le Conte Club.

ELECTION OF OFFICERS

The following officers were elected to serve during 1926:

Chairman, Eliot Blackwelder
Secretary, John P. Buwalda
Councilor, William T. Miller

PRESENTATION OF PAPERS

The meeting was called to order at 2.00 p. m. by the Chairman, Eliot Blackwelder. Dr. Blackwelder then requested Dr. C. F. Tolman to take the chair and conduct the symposium arranged by him at the invitation of the Executive Committee.

SYMPOSIUM ON SILICEOUS SHALES AND ORIGIN OF PETROLEUM IN CALIFORNIA

C. F. TOLMAN, LEADER

OPAL AND ITS RELATION TO OTHER FORMS OF SILICA

BY AUSTIN F. ROGERS

DISTRIBUTION AND THICKNESS OF DIATOMACEOUS SHALES

BY B. N. NELSON

Discussed by F. M. Anderson and W. M. Davis.

FOSSIL FISH AND THEIR BEARING ON THE SILICEOUS SHALES

BY DAVID STARR JORDAN

Discussed by C. F. Tolman, Robert Anderson, Roy E. Dickerson, and F. M. Anderson.

FOSSIL BIRDS AND THEIR BEARING ON THE SILICEOUS SHALES

BY LOYE HOLMES MILLER

Discussion by Messrs. Jordan, W. M. Davis, Robert Anderson, Touwaide, and Crawford.

FRESH-WATER AND MARINE DIATOM EPIDEMICS

BY L. B. BECKING AND H. C. MCMILLIN

Discussed by Messrs. Tolman, W. M. Davis, G. D. Hanna, Hodge, Palmer, and F. M. Anderson.

OCCURRENCES OF SILICEOUS SHALES IN THE SANTA MARIA BASIN

BY B. F. HAKE

Discussed by Messrs. Tolman, F. M. Anderson, and Ickes.

PHOSPHATE BEDS IN THE MONTEREY SHALES

BY R. D. REED

(*Abstract*)

In two Coast Range areas more than 75 miles apart thin beds of oolitic phosphate rock in the Monterey shale have recently been discovered. One locality is north of the La Panza Range, in San Luis Obispo County; the other is in Vaquero Canyon, in Monterey County. The latter appears to contain the greater quantity of phosphate rock, but neither locality has yet been exhaustively studied. The phosphate occurs as more or less distorted oolitic

opal shale. It is isotropic and has a refractive index near 1.60. The oolitic beds are from 4 to 6 inches thick and are continuous at least for distances of several yards. They are separated by thicker, fine-grained beds, some of which contain a little collophane.

In the Vaquero Canyon occurrence the phosphate beds are found near the middle of a 7,000-foot shale section which is largely calcareous and foraminiferal below, but is siliceous and diatomaceous in its upper portion. The phosphate beds may belong to the transition zone, but their stratigraphic relations need further study. On the basis of such study, and of a petrographic examination of the material, I hope at a later time to undertake a discussion of some of the sedimentational problems involved.

DIATOMACEOUS SHALE INTERBEDDED WITH ARKOSE

BY HUBERT G. SCHENCK

(*Abstract*)

Diatomaceous shale interbedded with arkose occurs on the eastern side of Gabilan Range, San Benito County, about five miles northeast of the Pinnacles National Monument, California. The arkose contains large boulders of granite and the shale is characterized by the presence of the diatom *Coscinodiscus*.

Discussed by Messrs. F. M. Anderson, Buwalda, Clark, Robert Anderson, Blackwelder, Woodford, R. D. Reed, and Hodge.

SUMMARY OF PROGRESS IN THE MICROSCOPIC STUDY OF THE SILICEOUS SHALES

BY C. F. TOLMAN

(*Abstract*)

The studies summarized have been in progress for over a year and a preliminary presentation of some of the results was made at the last meeting of the Le Conte Club. The microscopic examination showed that the organic deposits consisted originally of five types of material: 1, unbroken diatom tests; 2, diatom debris, the ultimate particle of which often consists of the single knob of the adornment of the diatom test; 3, sponge spicules; 4, opal gel; 5, impurities.

Rocks consisting entirely of material of types 1 and 2 may properly be denominated as diatomite. This is a massive pulverulent rock. In its purest form it has commercial value and sells under this name. In the Santa Maria district beds several hundred feet thick of massive diatomite form an important part of the stratigraphic column. The diatomite also contains from 5 per cent up to 15 per cent of sponge spicules and at Lompoc layers of rock composed largely of sponge spicules occur and constitute the so-called "filter rock" of the quarrymen.

Rocks composed largely of type 2—that is, cemented diatom debris—constitute what is commonly known as diatomaceous shale, which has been further defined as clayey diatomaceous shale. As a matter of fact, these

shales contain little clay, and their clayey nature is due to the fact that they contain no opal cement. The general term "opal shales" may well be applied to these rocks.

The third variety, of dense "splintery or porcelainous" shales, consists of diatom debris cemented by an opal gel. The latter can be distinguished from the opal of the diatom debris by a slight difference in the index of refraction. These rocks may also be called opal shales with the additional term of indurated or cemented. The opal gel occurs also in nearly pure form as bands, layers, and concretions. The layers and lamellæ of vitreous opal are considered to be the result of deposition of opal gel during sedimentation rather than a recrystallization due to diagenesis.

The diagenetic processes include first a recrystallization of opal gel to chalcedony, and later a recrystallization of the diatom debris and diatom tests. Calcareous material deposited with the diatoms is recrystallized to dolomite. Volcanic ash is largely unaltered. Slides illustrating these various types of sediments and their diagenetic changes were exhibited.

The bearing of these data on the origin of oil was discussed and among other things it was brought out that diatomite and uncemented debris are usually free from traces of oil, that the gel cemented opal shales often contain hydrocarbons, and that the recrystallization of opal to chalcedony and the crystallization of dolomite tend to drive the hydrocarbons out of the body of the rock into the cracks.

Discussion

Prof. Austin F. Rogers stated that in the formation of sedimentary rocks there are two general processes involved: sedimentation and diagenesis. The "vitreous opal" of Professor Tolman is, in the opinion of Professor Rogers, reformed opal that is a product of diagenesis. It often contains remnants of foraminifera with associated chalcedony. In these opal-bearing rocks the chalcedony is always a secondary mineral and it seems probable that the "vitreous opal" and the chalcedony were both formed after sedimentation.

HISTORY OF THEORIES REGARDING SILICEOUS SHALE AND THE ORIGIN OF OIL

BY FRANK M. ANDERSON

(*Abstract*)

In the oil districts of California there are many different types of organic deposits connected with the occurrence of petroleum, and as many different types of petroleum that are derived from them, when studied throughout the State. In order to determine the origin of the types of oil known, it becomes necessary to discriminate, keeping in mind the particular type of oil whose original source is in question.

S. F. Peckham proposed the following classification of bitumens:

1. Those bitumens that form asphaltum and do not contain paraffin.
2. Those bitumens that do not form asphaltum and contain paraffin.
3. Those bitumens that form asphaltum and contain paraffin.
4. Solid bitumens that were originally solid when cold or at ordinary temperatures.

Oils of the first class are the most common in California and form a great part of the production, past and present. They belong especially to those districts which are dominated by the siliceous, diatomaceous shales of the Miocene. These oils may therefore be regarded as having a vegetable source in the Diatomaceæ and associated plant forms, if any occur in these shales.

Only a very minor part of California petroleum carries hydrocarbons of the paraffin series, but a much larger portion contains unsaturated hydrocarbons, olefines, and napthenes. Oils of this type constitute the main body of the production coming from Ventura and the northern part of Los Angeles counties. If we assume that these oils represent the true paraffin class, they may be substituted for Peckham's second class.

They are chiefly characterized by hydrocarbons of the series CnH2n and do not contain asphaltum. They are found only in association with strata dominated by animal organisms, Foraminifera, etcetera, and may be regarded as having an animal origin. This type of petroleum formed the main part of the early production of California.

Oils that contain bases of both of the former classes can be traced to strata containing also both classes of organisms, either mingled in the same beds or existing in successive or alternating beds, from which the different oils issue and mingle in the production. This class of oil has had its origin in both animal and vegetable sources.

The solid bitumens referred to by Peckham result from the loss of gaseous and liquid portions of the original crude oil, and therefore should not be regarded as a distinct class.

Many other types of petroleum are known in California, occurring under conditions more or less special, of which the origin must be studied in the light of the facts pertaining to each and with reference to its peculiar geologic relations.

The first writer to definitely suggest Diatomaceæ as the source of petroleum in California, or, in fact, anywhere, was J. D. Whitney, former State Geologist, who concluded, 1865, 1867, from the known association and other evidences, that "the existence of bituminous materials in this State, in all their forms, from the most liquid to the most dense, is due to the presence of infusoria." By infusoria he meant only the Diatomaceæ of the "bituminous slates" known to him, following the rule of others of his time in this usage of the term.

Many writers since Whitney's time have been impressed by the same geologic relations and have made the same suggestions, connecting the bitumens with the siliceous, diatomaceous shales of the Tertiary in this State, either independently or otherwise.

The first writer to suggest an animal source for California petroleum was S. F. Peckham, who was a contemporary of Whitney, and in fact contributed to some of his reports, namely, Geology of California, volume II, 1868-1882. Later, Peckham recognized the probable derivation of at least a portion of the oil of California from vegetable sources and admitted that both animal and vegetable materials might be considered as the source of petroleum in this State.

Writers who have advocated the origin of California oil from Diatomaceæ since Whitney's time may be mentioned in the order of their publications, as

follows: Bernard Bienfield, 1897; W. L. Watts, 1897, 1900; F. M. Anderson, 1903, 1904; Ralph Arnold, 1907; Arnold and Robert Anderson, 1907; R. W. Pack, 1920.

The writers who have advocated the animal origin or a mixed origin, animal and plant, since the time of Peckham, are numerous, but less easy to follow. They include Frederick Salathe, 1897; W. L. Watts, 1900; Hans Hofer, 1914, etcetera.

Outside of California Diatomaceæ may have been first suggested as a source of petroleum by Dr. Otto Witt, professor in the Royal Technical High School, Berlin, 1894. Kramer and Spilker have been given this credit, but their writings date somewhat later, 1900-1902. F. W. Clarke, reviewing the subject in 1908, gives the chief credit to A. F. Stahl, 1899, and to Kramer and Spilker.

It may be shown that many, though not all, of the great oil regions of the world conform to the requirements of the view here proposed.

ORIGIN OF OIL FROM MARINE PLANKTON SHALES IN CALIFORNIA

BY ROBERT ANDERSON

(*Abstract*)

The theory is here reaffirmed that most of the oil in California originates in the shales characterized by the remains of minute marine organisms, chiefly diatoms and foraminifera. This theory, originally founded on the close relation of petroleum deposits and seepages to what was regarded as one formation of such shale, of Miocene age, was by successive steps confirmed through the discovery of several thick formations of similar character but different age, ranging from Upper Cretaceous to Upper Miocene, with each of which petroleum is intimately associated. These formations comprise thicknesses of organic shale ranging from a thousand to over five thousand feet.

In the Santa Maria oil field the principal oil-bearing formation is the Monterey shale (Middle Miocene). In the Coalinga field the principal shales are not Monterey, but Kreyenhagen, of Oligocene age. A lower formation of diatomaceous shale, the Moreno, also oil-bearing, is of Cretaceous age. Each of these two horizons in the Coalinga field has its own type of oil. In the Temblor Range and the southern California fields there are important oil-yielding shales of similar constitution dating from the Upper Miocene.

Thus there are at least four distinct formations of this type of Plankton shale, representing different periods of deposition, but each showing a petroliferous character and standing in the position of mother rock for large accumulations of oil.

Aside from these accumulations in the oil fields, the widespread occurrence of oil in the shales gives strong evidence of its indigenous origin. In the aggregate there are many thousands of miles of outcrop of such shale formations which characteristically show evidences of oil. At least as far north as Point Arena such shales occur and are bituminous, and at the next occurrence to the south, at Point Reyes, they are again oily. Some of the principal indications are: discolorations due to oil, evidence of the bituminous nature of the shales on being heated, seepages, veins and cavities filled with oil, interbedded and immediately adjacent sandstones impregnated with oil or asphalt.

The volume or organic debris represented by these deposits is enormous. They are largely composed of diatom tests and the derived silica, but foraminifera are an important constituent and are to be considered along with the diatoms as having been a source of the oil.

The petroliferous character of the shales prevails, regardless of a great variety of relationships to other strata. For instance, in places in the Santa Cruz and Salinas Valley regions the oil-bearing shales lie as they were deposited, on granite. Elsewhere, where lying between other formations, the shales have their characteristic petroliferous nature, whereas the other strata rarely contain indications of oil except within a comparatively short distance from the shales.

Thus, combining various different lines of evidence, no doubt can remain that the great bulk of the petroleum of California originated in this type of shale.

Discussion

Dr. W. M. Davis asked regarding the paleogeography at the time the shales were deposited. Mr. F. M. Anderson replied that there were many landlocked basins of which the Temblor and the Santa Maria are good examples.

Dr. Davis then asked how recent is the present topography. Dr. Bailey Willis said that the present uplift is recent and active, but is a replica of an older relief.

Dr. Bruce L. Clark remarked that the evidence is conclusive that one of the basins had shorelines at Monterey and in the neighborhood of Monterey.

Prof. C. F. Tolman emphasized the fact that local unconformities exist around the rising landmasses. The lines of the mountain ranges are lines of continuous growth. The deeper beds have a steeper dip and the overlying beds have gentle dips. Conformable series are formed in the basins and unconformities in the areas undergoing uplift. Mr. Tolman referred to Dr. John C. Branner's article, in which he describes the manner in which the old bays and estuaries opened northward and caught southward-flowing currents of cold diatom-bearing waters.

Mr. F. M. Anderson remarked that the volcanic ash of the Lower Miocene supplied silica for the diatoms.

ORIGIN AND ACCUMULATION OF OIL IN CALIFORNIA[1]

BY G. C. GESTER

(*Abstract*)

Too much has been taken for granted and not enough real work done nor thought given to the problems connected with the origin and accumulation of oil in California. This paper presents a plea that more consideration should be given to these problems, both for the benefit of pure science and for the more practical purpose of aiding in the discovery of new oil fields.

The following diagrams, made from data collected from 46 oil fields, were presented:

[1] Read by Roy E. Dickerson.

Types of Structure

Anticline.	Terrace or monocline.	Fault.	Syncline.
80.5 per cent	13.0 per cent	6.5 per cent	.....

Age of Reservoir Formations

Pliocene.	Miocene.	Oligocene.	Eocene.	Cretaceous.
60.8 per cent	19.6 per cent	17.4 per cent	.....	2.2 per cent

Age of Source Rocks

Miocene.	Oligocene.	Eocene.	Cretaceous.
74.5 per cent	4.2 per cent	19.2 per cent	2.1 per cent

There are also six fields where the Pliocene contains strata which might be classed as source rock.

Types of Reservoir Rock

Sandstone or sandy shale.	Fractured rock.
95.7 per cent	4.3 per cent

It was further pointed out that in several of the fields listed there are two formations from which the oil is produced, and also there are several fields in which there exist two formations which might serve as a source of oil.

In practically all of the California fields there are thick shale formations more or less intimately associated with oil-bearing horizons. In a number of cases, however, there are hundreds of feet of clays and clay shales, with occasional sandy beds, between the top of the shales and the base of the oil measures. In other cases the oil measures themselves rest on the shale formations.

Excepting for comparatively isolated cases, the origin of the oil *in situ* is doubted, but the question is raised as to whether or not the organic material might not have been changed to some type of oil contemporaneously with the deposits and the original characteristics of the organic material entirely destroyed. In practically all fields it is noted that the thick shales underlie the reservoirs which are near-shore sand and sandy shale deposits. The general unconformity at the top of the shales in each case is regional and sandstones lie on beveled shales. The unconformity is also shown by change in form. If the shales are the source of the oil, the question is raised as to how and when the change took place from the original organic material, and what were the factors governing its migration from the source into the reservoir rock.

The Miocene shales have been classed in California as being the most important source rock. These shales attain thicknesses of over 5,000 feet. In some localities they contain a little oil in a free state; in other places, oil can be derived from the shales only by distillation processes. In many localities, however, no oil can be obtained from the shales by either titration or distillation. In some cases the latter condition is true of the shales which immediately underlie oil measures. Furthermore, some of these shales are highly diatomaceous. In other places they are almost devoid of fossil remains. It is further interesting to note that there are cases where rich diatomaceous shales hundreds of feet thick are overlain by an adequate reservoir rock in

which there are favorable structural conditions that have been adequately tested and no oil found.

In other localities comparatively small thicknesses of foraminiferal shales are found immediately associated with the oil measures. These are in turn separated from formations of diatomaceous shales by several hundred feet of sediments.

The data presented are somewhat conflicting and the question arises, Were the diatoms in part or the only ultimate source of the oil, or should we look further for some other type of organic matter from which the bulk of the California oil may have had its origin?

Session of January 30

PRESENTATION OF PAPERS

MARINE OLIGOCENE OF OREGON

BY HUBERT G. SCHENCK

(*Abstract*)

Reasons are adduced for discarding Astoria as the type locality of the Oligocene of the Pacific Coast. However, strata of Oligocene age are present in Oregon, as a study of the stratigraphy in the vicinity of Eugene and Yaquina Bay proves. Moreover, the fauna of the Oligocene of Oregon is distinctive and is correlated with the fauna of the Oligocene of Washington and California.

Read from manuscript and illustrated by lantern slides.

TERTIARY OF THE PUNJAB

BY ROBERT ANDERSON

(*Abstract*)

A brief description of the four- or five-mile-thick, non-marine, Tertiary series which unconformably overlies the marine and estuarine Eocene in northwestern India. The non-marine series, separate divisions of which are known by separate names, is essentially one, representing fairly continuous alluvial-plain deposition during Miocene-Pliocene and probably also Oligocene times, on a gradually subsiding plain south of the Himalayas. This series affords evidence of the existence of an Himalayan Range during its deposition, but there is also evidence of severe post-Tertiary uplift and deformation. A well in the Punjab recently completed to a depth of six thousand feet gives excellent confirmation of the thickness measurements, and other features assumed from surface study, in this thick series.

Presented extemporaneously.

NATURE AND ORIGIN OF THE "BROWN ROCK" PHOSPHORITES OF TENNESSEE[1]

BY AUSTIN F. ROGERS

(*Abstract*)

The "brown rock" phosphorite, or phosphate rock, of south central Tennessee is formed by weathering and leaching of the calcite from phosphatic limestones of Ordovician age. The phosphatic limestones are made up of angular to rounded fragments of crinoid stems, bryozoans, gastropods (*Cyclora*), brachiopods, ostracods, and ostracoderms. Some of the fragments are entirely calcite, some entirely collophane, but in many the network of the crinoid or bryozoan is calcite and the meshes collophane. This mesh collophane of the first generation was doubtless formed while the fragments were rolled about on the sea-bottom before consolidation of the limestone.

During the formation of the phosphorite the network calcite was replaced by collophane of the second generation. The phosphorites contain no calcite, although analyses show a fair percentage of calcium carbonate.

At a relatively late stage dahllite, the crystalline equivalent of collophane, was deposited in colloform crusts and occasionally in distinct euhedral crystals in cavities, and along with it brown, doubly-refracting collophane of the third generation appeared. In some cases the network collophane of the second generation gave place to "fuzzy" dahllite. In all cases dahllite is a secondary mineral of minor importance.

Presented extemporaneously and illustrated by lantern slides. Discussed by Prof. C. F. Tolman.

NORMAL FAULTING ON UPTHRUST ARCHES

BY BAILEY WILLIS

(*Abstract*)

The occurrence of normal faults in regions characterized by typical folding, as in the Appalachians, is extremely rare and appears to be inconsistent with the development of folds as a result of horizontal compression transmitted by the strata themselves. Having been trained in the Appalachians, the writer consistently questioned the occurrence of normal faults in the Coast ranges and Sierra Nevada because the dominant structures of those mountains are the result of compression, and the contradiction between them and the tension implied by normal faults appeared to exclude the latter. Detailed studies of the Sierra Nevada and Owens Valley have, nevertheless, demonstrated the existence of normal faults as a fundamental structure of that mountain range and have led the writer to a new interpretation, namely, the Sierra Nevada has been tilted and up-arched by vertical forces, which are in turn the effect of deep-seated horizontal compression. This hypothesis has general application in the explanation of

[1] Presented with the permission of the State Geologist of Tennessee.

grabens and connects arched structures with plateau uplifts as possibly having a common genesis.

Presented extemporaneously. Discussed by Messrs. Clark and Buwalda.

MINERALOGIC AND CHEMICAL CLASSIFICATION OF IGNEOUS ROCKS

BY EDWIN T. HODGE

(*Abstract*)

Presentation of a classification of over one thousand species of igneous rocks, showing that all these rocks may be classified by their mineral composition in such a way that their chemical composition will be revealed, or that, if classified chemically, their mineralogic composition will be shown. Rocks classified either by mineral or by chemical composition will fall in the same place in the classification. The classification is so designed that it can be presented upon a single plane. The classification creates no new terminology and does not require for its use any elaborate mathematical calculations.

Presented extemporaneously. Discussed by H. W. Turner.

GEOLOGY OF THE OREGON CASCADES

BY EDWIN T. HODGE

(*Abstract*)

A history of that portion of the Oregon Cascade Range lying between the Three Sisters and Mount Jefferson. Evidence is offered to show that Eocene and older rocks lie beneath the Cascade Range; that the marine Oligocene of western Oregon represented by the Toledo and Yaquina formations are the same as the marine Oligocene of the Willamette Valley and that they extend under the Cascade Range; that the volcanic pyroclastic of Oligocene age may be found in eastern Oregon; that the Miocene lava flows represent a continuation of the Oligocene vulcanism and have been chiefly responsible for the building of the Cascade Range; that in early Pliocene time the simple volcanic range took part in a general eastward tilting of the Oregon block, so that the westward-dipping lavas were brought to a position of horizontality and the dip of the eastern lavas was steepened. Erosion of early Pliocene time dissected the lava plateau to a state of advanced maturity. The concordance in elevation of the peaks is due to the fact that they are remnants of this whole lava surface and do not represent peneplanation. The material eroded in early and later Pliocene time may now be found as remnants of old coastal plains in the Empire and Coos Bay formations along the coast. The Middle Pliocene was a period of stability, whereby the valleys were broadened. During Middle Pliocene time many of the high volcanoes of Oregon were erected, particularly those of the Three Sisters, Mount Washington, Three-Fingered Jack, and Mount Jefferson. The rocks erupted at this time were andesitic to trachytic and syenitic in character. Late Pliocene time was devoted to erosion, whereby these peaks were sculptured and the

valleys were deepened. Another uplift took place in early Pleistocene time, producing glaciation and vulcanism. The rocks erupted at this time are basalts. The glaciers of early Pleistocene time covered the entire Cascade Range and were much more extensive than those of any other period and are correlated with the Admiralty glacial epoch of Washington. Due to the heavier rainfall and the melting of the Admiralty glaciers, the valleys of western Oregon were deepened and the eroded material deposited along the coast as a lower part of the Elk River formation. The Middle Pleistocene epoch is an interglacial epoch. During this time the valleys were aggraded, so that silts filled the valley of the Willamette River to depth in places of 300 feet. The glacial erratics found in the Willamette Valley are explained. This epoch is correlated with the Puyallup in the State of Washington. The third portion of the Pleistocene brought about a renewal of glaciation, which is correlated with the Vashon of the State of Washington. This glaciation was not so intensive as that of the Admiralty. The rivers of western Oregon were rejuvenated and dissected much of the aggraded floodplain of the Puyallup epoch. The Pleistocene in general was a period of more warmth than at the present time, permitting Oregon to be occupied by camels, mastodons, sloths, horses, and by a warmer flora. The great storage of ice on the high Cascades during the Pleistocene supplied the western winds with moisture and permitted the development of lakes in eastern Oregon. The two lake periods of eastern Oregon are to be correlated with the Admiralty and Vashon glaciation. The two periods of desiccation are correlated with the Puyallup and the Recent. At the close of the Pleistocene, vulcanism was renewed in the Cascade Rage and has continued down to the present time. As a result, there have been built over fifty volcanic cones and many great lava-flows veneer the surface. These lava-flows have deranged the drainage and developed many of the high mountain lakes. The glaciers are decreasing in size, due to a depression of the Oregon block. The lakes in eastern Oregon are disappearing, the streams are again aggrading their beds, the rivers are drowned, and the climate is getting drier and less warm.

Presented extemporaneously. Discussed by J. P. Buwalda.

SOUTHERN NEVADA EARTHQUAKE OF AUGUST 21, 1925, AND CALIFORNIA EARTHQUAKE OF JULY 19, 1925

BY PERRY BYERLY

(*Abstract*)

By the use of the tables of A. Mohorovicic, recently issued, and the seismograms of Berkeley, Mount Hamilton, and Reno, the depth of focus of the Nevada earthquake of August 21, 1925, 3 hours, 14 minutes, 15 seconds, Pacific standard time, if found to be about 12 plus or minus 2 kilometers and the position of the epicenter a few kilometers north of McNamara Lake, in the Benton Range. The depth of focus of the California earthquake of July 19, 1925, 11 hours, 25 minutes, Pacific standard time, if found to be about 24 plus or minus 2 kilometers, and the epicenter on the Hayward Fault about 3 kilometers south of Evergreen. The determination of the depth of focus

is dependent on the measurement of time intervals to accuracy greater than to the nearest second, and with the type of instruments available in this study such accuracy is not generally obtainable. The limits of error in times are discussed.

Read from manuscript. Discussed by J. C. Jones.

CLOSED VALLEY HYPOTHESIS: AN EXPLANATION FOR IMBRICATED STRUCTURE AS SEEN ON THE MOUNT DIABLO THRUST

BY B. L. CLARK

Presented extemporaneously. Discussed by Messrs. Tolman, Turner, Dickerson. W. M. Davis, Hake, and Tonwaide.

STRATIGRAPHIC CONSIDERATIONS OF THE UPPER PALEOZOIC FORMATIONS IN EASTERN UTAH

BY ASA L. MATHEWS

(*Abstract*)

A brief correlation of the formations representing the three major divisions of the Upper Paleozoics is made, showing relationships. The paper points out local differences in the sequence of formations, showing differences in deposition and structure. Special mention is made of the unconformities of the series.

Read from manuscript.

NEW LIGHT ON THE BASIN RANGE PROBLEM

BY WILLIAM MORRIS DAVIS

Presented extemporaneously. Illustrated by lantern slides. Discussed by Messrs. J. C. Jones and Crawford.

SLOPE OF BASIN RANGE FAULTS AND SCARPS

BY JOHN P. BUWALDA

(*Abstract*)

The range-producing faults of the Great Basin have generally been considered to be normal in character. This belief does not appear ever to have been demonstrated inductively on the basis of an adequate number of recorded or published observations on the direction and degree of dip of the fault-planes. An attempt is made in this paper to do this through use of observations by the writer and others.

It has often been held that triangular facets on fault-scarps approach in position and slope the faults at their bases. Observations by the writer do not confirm this conviction.

Read from manuscript. Discussed by Messrs. W. M. Davis, J. C. Jones, and C. F. Tolman.

PIRACY AND THE PERSISTENCE OF ANTECEDENT STREAMS ON THE LOS ANGELES COASTAL BELT

BY FREDERICK P. VICKERY

(*Abstract*)

There are three airgaps on the Los Angeles coastal belt which show that the headwaters of the streams which formed them have been diverted by piracy or similar process. On the divide between the streams which now drain Cahuenga pass are stream gravels. This pass, Coyote Pass, and a small pass between Signal Hill and Los Cerritos have cross-sections that are characteristic of stream-work. These airgaps traverse recent uplifts. Inland from the passes the streams cross structural depressions which have been filled by alluvial fan deposits. Diversion of these headwater streams may have occurred as a result of (1) piracy, in which the pirate was favored by a course in a relatively depressed area; (2) ponding and overflow along a structural depression, or (3) migration of a distributary on an alluvial fan from the pass to a structural depression.

Between the Los Angeles Basin and the Pacific Ocean there is a complexly anticlinal uplift which extends from Beverly Hills to Newport. Antecedent streams traverse this uplift through watergaps. These streams are Ballona Creek, Los Angeles River, San Gabriel River, Santa Ana River, and a small creek that empties into Newport Bay. Northeast of the uplift the basin has been sinking and has been filled by alluvial fan deposits. These streams flow from the mountains over the alluvial fans to the watergaps and thence to the ocean. They are at liberty to swing radially on their fans, and in some cases have changed from one watergap to another. Evidently the supply of sediment brought down from the mountains has been adequate to fill the basin as it formed, because otherwise ponding would have occurred and the basin would have one or possibly two outlets. The persistence of five outlets is remarkable, because they have survived despite the danger of ponding and the wandering of distributaries.

Presented extemporaneously.

SCARP AT THE MOUTH OF THE KERN RIVER CANYON

BY ELIOT BLACKWELDER

(*Abstract*)

At the mouth of the Kern River Canyon, east of Bakersfield, California, there is a bold mural slope which is trenched by the river in a narrow, V-shaped notch. Gilbert and others have considered this a true fault-scarp.

The writer's study of the surrounding area indicates that the present topographic forms are due to erosion upon a faulted mass. The feature is therefore diagnosed as a fault-line scarp.

Read from manuscript. Illustrated by lantern slides. Discussed by Messrs. Crawford, Hake, W. M. Davis, Robert Anderson, Louderback, and Vickery.

ANNUAL DINNER

The annual dinner was given at the Stanford Union, under the auspices of the Le Conte Club, and approximately forty-two Fellows and guests participated.

REGISTER OF THE 1926 MEETING

FELLOWS

F. M. ANDERSON
ROBERT ANDERSON
ELIOT BLACKWELDER
JOHN P. BUWALDA
B. L. CLARK
WILLIAM M. DAVIS
ROY E. DICKERSON
K. C. HEALD
A. S. EAKLE
G. D. LOUDERBACK
R. W. PACK
A. F. ROGERS
SOLON SHEDD
W. S. T. SMITH
H. W. TURNER
BAILEY WILLIS

In addition to the foregoing, there were registered at the meeting 60 guests, many of whom took part in the program and discussion.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 38, PP. 209-216 MARCH 30, 1927

PROCEEDINGS OF SECTION E OF THE AMERICAN ASSOCIATION FOR THE ADVANCEMENT OF SCIENCE

GEORGE R. MANSFIELD, *Secretary*

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SESSION OF SECTION E

Section E of the American Association for the Advancement of Science held a series of meetings in Philadelphia, Pennsylvania, December 28-30, 1926. The Chairman of Section E for the year 1926 was George H. Ashley, who was also a Vice-President of the American Association. The retiring Chairman was Reginald A. Daly.

The following papers were read at the meeting by Fellows of the Geological Society of America:

TITLES AND ABSTRACTS OF PAPERS BY FELLOWS OF THE GEOLOGICAL SOCIETY OF AMERICA

GLACIAL STUDIES OF FRANK LEVERETT OUTSIDE OF THE LEWIS AND WRIGHT GLACIAL BOUNDARY IN PENNSYLVANIA

BY GEORGE H. ASHLEY

(*Abstract*)

In the absence of Frank Leverett, Mr. Ashley, State Geologist of Pennsylvania, presented informally some of Mr. Leverett's findings during the last summer outside the Lewis and Wright glacial boundary in Pennsylvania—a cooperative study made by the State and the United States Geological Survey.

Aside from retracing a very considerable part of the Wisconsin border, making detailed corrections where necessary, Mr. Leverett devoted most of his time to a study of the evidences of earlier glaciation outside that border. In the northwestern part of the State the evidence seems clear that glaciation of Illinoian age reached farther south and east than that of the later Wisconsin. Certain deposits were thought by Mr. Leverett to be of even greater age than the Illinoian. In eastern Pennsylvania the glacial border was examined from the neighborhood of Lock Haven eastward to the Delaware River. In the region between Lock Haven and Sunbury clear evidence of very early glaciation was found, extending up the mountains to elevations of above 1,100 feet in areas where the Wisconsin outwash reached only about 600 to 640 feet. One of the most interesting findings was a tongue of Wisconsin till extending down the North Fork past Sunbury and Selinsgrove, ending in a definite moraine west of Selinsgrove.

In the Lehigh region morainic topography south of Bethlehem, in the Saucon Valley, gave evidence of Illinoian age. The morainic topography is young, but the deposits themselves appear older than the Wisconsin. West of Allentown it was found that the glacier had not extended to the Schuylkill River, as had been thought previously, but ended with a definite morainic border a few miles west of Allentown.

On the Susquehanna it appeared to be definitely established that the lower terraces, those within 100 to 120 feet of the present river level, are mainly, if not entirely, of Wisconsin age. Gravels were also found on numerous hilltops at elevations of up to 600 feet above tide, or 300 feet above present river level, which appeared to correlate with and be derived from drift of very early glacial time. The presence of these gravels 300 feet above present river level opened up an interesting question as to the extent of valley down-cutting since they were laid down. Were they laid down by a river flowing at about that level on top of an aggraded valley; were they laid down in a valley not yet deepened, or were they deposited by floating ice in ponded waters? For the State Geologist the problem has a broader aspect in the association of these gravels with what has been called the "Harrisburg peneplain." Within a few miles of Harrisburg are nearly a thousand hilltops lying between 500

and 560 feet above sealevel. Some of these hilltops are strikingly flat and broad, at some places having a length of one or two miles, with a width of one-quarter to one-half mile or more within one 20-foot contour interval. Furthermore, these flat-topped hills carry over from the Susquehanna to the Potomac and indicate a condition in which apparently there may have been sea incursion or else a graded peneplain condition. The association of early glacial gravels with this condition opens up unlimited problems covering the whole physiography of the Atlantic Coastal Plain and the age of the gravel and other deposits found on that plain. Incidentally, it may turn out that we have a new opportunity of calculating the time since the earliest advances of the ice, in the measure of valley erosion that has taken place since that time. Its obvious bearing on the age of man is only one side of the problem. It is hoped that the studies can be continued another year.

STRUCTURAL AND PHYSIOGRAPHIC FEATURES OF THE PIEDMONT PROVINCE OF PENNSYLVANIA

BY F. BASCOM

(*Abstract*)

A model of an area about 11 miles wide and 55 miles long extending across the Piedmont province in Delaware and Pennsylvania, with structure-sections, was displayed and interpreted. The berms (remnants of straths and benches) and peneplain remnants of the Piedmont province of Pennsylvania were briefly described with the use of maps, profile sections, and lantern slides.

CLIMATIC PULSATIONS IN MONGOLIA

BY CHARLES P. BERKEY AND FREDERICK K. MORRIS

(*Abstract*)

The Lower Cretaceous formations of Mongolia, Siberia, and northern China include black and gray shales and water-laid sands containing a fauna of water-loving reptiles, fishes, and insects. The Cretaceous Djadokhta formation, consisting chiefly of wind-blown sands carrying a plains-living fauna, indicates a change toward a more arid condition.

The Tertiary opens with somewhat more humid climate, as is shown by the nature of the formations. A change toward increasing aridity, culminating in the desert conditions of Oligocene time, is again supported by the fauna. Another increase in rainfall is suggested by the presence of mastodons in the Miocene and Pliocene, and of beavers, frogs, and other water-loving forms in the Pliocene.

The Pleistocene deposits suggest at least two moist and two dry epochs. Great alluvial fans were accumulated during the dry epochs and were deeply eroded during the intervening, more humid ones. The range Ikhe Bodgo was glaciated. The glacial gorges were trenched by post-Glacial streams, which have also dissected the older alluvial fans. The periods of glaciation, as well as those of active dissection, are believed to indicate moist climatic conditions. The highest shorelines of the lakes are probably of Pleistocene age. Diminishing water is recorded by successively lower beaches.

The post-Glacial Shabarakh formation of sands and clays chokes valleys where streams flowed during late Pleistocene time. The lower beds are water-borne, the higher sands are windblown. A drying climate, grading into present desert conditions, is indicated. More recent minor oscillations of climate are suggested by the increase in the "badland" type of dissection, by the shrinking of forests, and by the drowned trees revealed by the drying of lakes.

TWO GLACIATIONS WITHIN THE LAND-RIBBON SURROUNDING THE INLAND ICE OF GREENLAND

BY W. H. HOBBS

(*Abstract*)

The broadest section of the land-ribbon surrounding the inland-ice of Greenland is within the Holstensborg district on the west coast near the Arctic Circle. This area appears to have been glaciated throughout, but there is evidence that a large part of the hinterland has been glaciated more than once. This evidence is found in the later stage of glacial denudation of the inner zone, the perfection of glacial polishing and striation, in the nature of the deposits, etcetera. The measure of the additional denudation is indicated not only in the relief forms, but in the relative altitudes of cirques. The nature of glacial sculpturing within the land-ribbon of Greenland is quite different from that where a continental glacier overrides a prairie country.

STRUCTURAL FEATURES OF SOUTHEASTERN IDAHO

BY GEORGE ROGERS MANSFIELD

(*Abstract*)

Detailed studies of an area of more than 3,000 square miles in southeastern Idaho, together with reconnaissance observations by the author in other parts of the northern "Rockies," have disclosed intense folding and remarkable overthrust faulting. Recent field-work has increased knowledge of the Bannock overthrust and tends to confirm the view that this fault is related to other great overthrusts, which together form a zone of overthrusting fairly continuous along a front aggregating perhaps 1,000 miles in the United States and Canada.

PRESENT STATUS OF SOIL DEFINITION AND GROUPING IN THE UNITED STATES

BY C. F. MARBUT

(*Abstract*)

The paper consists of two parts: The first part traces the development of ideas regarding soil definition during the last quarter of a century, from a stage characterized by an almost total absence of internal self-reliance up to a stage in which approximately full reliance is internal rather than external. During the emergence and in proportion to the extent to which that has taken place, it has been possible to develop principles and formulate generalizations on the basis of the accumulated data, establishing and consolidating in this way a position as a member of the family of natural sciences.

The second part of the paper outlines briefly the scheme of soil grouping or classification now in course of development, based on the definition of units described in the first part. It traces the development from a stage, in which definition of units and determination of relationships between units were based primarily on features of other sciences, to the present stage, in which both are based almost entirely on characteristics of the bodies themselves rather than on characteristics or forces pertaining primarily to some other science.

INFLUENCE OF SUBSIDUARY DISLOCATIONS IN THE STRATA OF THE GRAND CANYON ON THE DEVELOPMENT OF ITS TOPOGRAPHY *

BY F. E. MATTHES

(*Abstract*)

The detailed topographic surveys that have been made of the Kaibab section of the Grand Canyon bring out the fact that subsidiary faults, mostly of small throw, determine the loci of numerous side canyons and gulches within the chasm, and account for practically all of the constrictions and gaps that occur in spurs and between buttes. The existence of these subsidiary fractures, which are difficult for the eye to detect at a distance, is definitely attested by the elevations that have been determined for thousands of points on the edges of rock terraces. The Kaibab section of the Grand Canyon thus is found to be fairly criss-crossed by lines of fracturing, and it is to this fact that it owes the labyrinthine intricacy of its sculpture and, in large measure also, its surpassing scenic grandeur. The controlling influence of the fractures on the development of the topographic forms is nowhere more strikingly manifest than at the extreme head of the Grand Canyon. At this point, where the significant fracturing of the strata begins, the chasm flares abruptly from a width of a mile and a half to a width of fully eight miles.

GEOLOGY OF LARGE SPRINGS

BY O. E. MEINZER

(*Abstract*)

According to the best information at present available, there are in the United States 65 springs of the first magnitude—that is, springs which have an average yield of more than 100 cubic feet per second, or about 65,000,000 gallons a day, which is approximately the consumption of Washington, D. C. The largest of these springs yields nearly enough water to supply New York City. A detailed report on these springs is now in press and will be issued by the United States Geological Survey as Water-Supply Paper 557. It is often difficult to determine what constitutes a unit spring, for what is called a single spring in one locality may be equivalent to what in another locality is regarded as a group of springs, each of which has an individual name. Moreover, some springs fluctuate greatly, whereas others are nearly constant, and one spring may be at a high stage when another is at a lower stage.

* This paper was read by title.

Thus the discharge of a spring can be determined with fair accuracy only by establishing a gaging station and obtaining a continuous record over a period of years. Only a few of the large springs in the United States have been thus accurately gaged.

Of the 65 springs of the first magnitude, 38 issue from volcanic rock or closely associated deposits, 24 from limestone or dolomite, and 3 from sandstone. Of the 38 springs that issue from volcanic rock, 16 are in Oregon, 15 in Idaho, and 7 in northeastern California. Several have yields of more than 500 cubic feet per second. Among the largest are the Thousand Springs, in Idaho, and the Opal Springs, in Oregon. The volcanic rock is all of Tertiary or Quaternary age and is commonly basalt, but Big Spring, Idaho, which flows nearly 200 cubic feet per second, issues chiefly from rhyolite and obsidian like that of Obsidian Cliff, in Yellowstone National Park.

Of the 24 limestone springs of the first magnitude, 8 issue from early Paleozoic limestone or dolomite in the Ozark region of Missouri and Arkansas, 1 from Paleozoic limestone, or dolomite, in Alabama, 4 from Cretaceous limestone in Texas, and 11 from Tertiary limestone in Florida. Silver Spring, in Marion County, Florida, is probably the largest limestone spring in the United States. In four measurements its flow averaged 579 cubic feet per second. The largest spring in the Ozark region is either Big Spring, with an average in a 12-month record of 428 cubic feet per second, or Greer Spring, with an average in a 22-month record of 392 cubic feet per second. The largest spring in Texas is Comal Spring, which in 15 measurements averaged about 350 cubic feet per second.

The three sandstone springs of the first magnitude are in Montana and issue from rocks of Jurassic and Cretaceous age (Ellis and Kootenai formations). The largest are the Giant Springs, near Great Falls, which flow about 600 cubic feet per second, about two-thirds of which appears in the bed of Missouri River. These springs apparently owe their great discharge to faults or other structural features rather than to the permeability of the sandstone itself. Many large springs in various parts of the country issue from deposits of sand and gravel, but according to available information none of these can be classed as springs of the first magnitude except one or more of the group of springs in Idaho known as the Portneuf Springs. This group yields about 1,400 cubic feet per second, largely from gravel, but the water is probably supplied by the underlying basalt, and therefore in the above enumeration these springs were included with the springs in volcanic rock.

Many of the large springs from volcanic rock appear where the jointed and permeable water-bearing volcanic rock rests on an ancient land surface which has been buried by the lava. Thus the ground water may follow the preexisting stream courses and may produce large springs where these old stream courses appear at the surface. Many of the immense basalt springs on Snake River issue from the canyon walls 100 to 200 feet above the river. The Giant Springs are believed by C. A. Fisher to be due in part to diversion of water from Missouri River through a preglacial channel.

Faults cause a few of the large springs, partly by providing large openings through which the water can ascend and partly by forming underground dams

which bring the water to the surface. According to W. R. Calvert, Warm Spring and Lewistown Big Spring, in Montana, owe their existence to faults, and according to C. A. Fisher a fault may also occur at the Giant Springs. The limestone springs of the first magnitude in Texas occur along the Balcones fault zone, as was shown long ago by R. T. Hill and T. W. Vaughan. They are doubtless due partly to the openings provided by the fault fissures and partly to the head of water produced by the upland back of the fault-scarp. Faults are also involved in some of the basalt springs and in many of the large springs in the Basin and Range Province that do not rank as springs of the first magnitude..

In a region of limestone or other soluble rock there is an underground erosion cycle that produces a sort of underground peneplain comparable to the surface erosion cycles and peneplains in other regions. Many limestone regions have both surface and underground drainage systems, but in extreme cases all the surface water sinks. The character of the underground drainage system and the size of the springs depend largely on the lithologic character of the limestone and on the size and arrangement of its joints. The dip of the limestone is, however, not necessarily a controlling factor, for an underground drainage system may cut across the limestone strata regardless of the structure, provided there are no interbedded strata of insoluble, impermeable rock. A nearly complete underground drainage system may be developed, with very cavernous rock above the level of the underground drainage and tight rock below this level. It lacks storage capacity and discharges its water swiftly after a rain. Its outlets form springs that fluctuate violently, in extreme cases discharging torrents of muddy water in wet periods and becoming entirely dry in periods or drought. If the region is elevated, a new cycle of underground erosion may be started with a much lower baselevel, and the old underground peneplain may gradually be destroyed, very much as a surface peneplain is attacked by the head-end erosion of rejuvenated streams. Where a limestone country has subsided with reference to sealevel or the baselevel of the underground drainage has for some reason been raised, great systems of caverns may be submerged beneath the water-table and may function as huge subterranean reservoirs that equalize the discharge of the springs somewhat as a lake equalizes the discharge of a stream that flows through it. Limestone springs of this type are perennial and relatively constant, and they discharge clear water even at times of heaviest rainfall.

Of the limestone springs of the first magnitude in the United States, those in the Ozark region have somewhat the character of the fluctuating type, and those in Florida belong rather to the relatively constant type. A more extreme example of the fluctuating type is afforded by the Fontaine Vaucluse, which is the largest spring in France.

Fluctuation in the flow of springs is due almost entirely to variability in precipitation, atmospheric temperature, and other weather conditions. The amount of fluctuation is, however, affected by the topography, the rock structure, and especially the kind of rock, which determines chiefly the size and character of the openings through which the ground water passes. Springs in limestone are notably variable in their discharge. The fluctuations of the large limestone springs, whether in Missouri, Texas, or Florida, are, as a rule,

much greater and more sudden than those of the springs in volcanic rock, whether in Oregon, Idaho, or California. This difference is probably in part due to the fact that the openings in limestone were produced by the underground streams, and hence are adapted for carrying water, whereas the openings in the volcanic rock were formed in other ways, and therefore do not conduct the water so freely and directly.

As a rule, the water of very large springs is not highly mineralized, Salt Spring, in Florida, apparently being an exception. The water of most large springs in volcanic rocks is remarkably low in dissolved mineral matter, and even that of the large limestone springs is generally only moderately hard. To produce such large springs, the water must flow rapidly through large openings, and hence is not brought into very intimate contact with the rock. The mineral matter that is dissolved becomes diluted by the great volume of water.

With few exceptions, the springs of the first magnitude have temperatures that are not much above the mean air temperatures of the regions in which they occur. The large amount of heat required to raise greatly the temperature of so much water is not generally available in the rocks of any locality. In general, the water discharged by the very large springs is meteoric water that has not reached depths of more than a few hundred feet below the surface. Probably Warm Spring, in Montana, and Ana River Spring, in Oregon, both of which have temperatures about 20 degrees Fahrenheit above the normal, have the deepest sources among the springs of first magnitude in the United States.

PROGRESS ON A TECTONIC MAP OF PENNSYLVANIA

BY GEORGE W. STOSE

(*Abstract*)

A study of the tectonics of Pennsylvania has been begun and there was exhibited a map showing the larger known faults and the axes of the major folds of southeastern Pennsylvania. On this map the large positive masses and the Triassic negative masses are also outlined. The general structure was shown by structure contours. These preliminary maps were intended to show progress in the study and to obtain helpful suggestions for future work.

POSSIBLE POST-CRETACEOUS FAULTING IN THE APPALACHIANS

BY GEORGE W. STOSE

(*Abstract*)

The Kittatinny peneplain of supposed early Cretaceous age has been generally recognized on the tops of the Appalachian Mountains and Valley ridges in Pennsylvania, and the Schooley peneplain, of supposed later Cretaceous age, has been generally recognized at a considerably lower altitude on the hill tops of the Highlands of New Jersey and ridges of the Piedmont in Pennsylvania. No remnant of a higher peneplain to be correlated with the Kittatinny has been found in the Piedmont.

Northwest of Gettysburg the latest Triassic deposits consist of quartzose fanglomerates deposited at the foot of an uplifted fault-block now exposing chiefly Precambrian rocks, but in Triassic time capped by Cambrian quartzite and limestone. This uplifted mass is South Mountain of today. The minimum amount of this vertical displacement is 6,000 feet. There is strong evidence that there was uplift by faulting along this general line preceding the Triassic sedimentation, and it is known that there was uplift by faulting before the fanglomerate was formed and again at the close of the Triassic. Evidence is presented which tends to show that part of the 6,000-foot displacement took place after the Kittatinny peneplain was formed.

The suggestion is therefore offered that the Schooley peneplain in the Piedmont is the equivalent of the Kittatinny peneplain on the Appalachian Mountains and Valley ridges, and that their discrepancy in altitude, about 400 feet, marks the amount of post-Kittatinny or post-Cretaceous faulting.

STRUCTURE AND SCENERY IN WEST VIRGINIA

BY JOHN L. TILTON

(*Abstract*)

From Harpers Ferry, the gateway to West Virginia, one may travel westward by rail along the northern border of the State, or by auto he may follow the Valley of Virginia southward, and at Winchester turn westward toward Capon Bridge and Romney, or he may turn west just south of Harrisonburg and pass over the mountains to Franklin and to the mouth of Seneca Creek, or he may enter still farther south past White Sulphur Springs to Lewisburg, and then go either west past Charleston or south past Princeton, and then go northwest to Huntington.

Whichever path is taken the roads lie first over mountain ranges where strata rise on edge high into the air, through divides in massive horizontal ledges that cap synclinal mountains, through watergaps where vistas of fertile valleys open like great pictures set in a mountainous frame, and through gorges where swift streams have cut their way across and through great arches of massive ledges. Then, ever westward, the folds become less steep, rising to the even skyline of the Appalachian Plateau, and dissected by valleys often canyon-like, and often wide in regions of weak strata. Along broad terraces are large cities, centers of trade in regions of coal, oil, and gas, where mines dot the hillsides and oil derricks and gas wells mark the anticlines; then on out to the peaceful Ohio, rich in colonial history. Wherever one journeys from east to west there are to be seen the valleys and the beautiful mountains and hills of West Virginia—the geologist's paradise.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

PROCEEDINGS OF THE EIGHTEENTH ANNUAL MEETING OF THE PALEONTOLOGICAL SOCIETY, HELD AT MADISON, WISCONSIN, DECEMBER 27-29, 1926

R. S. BASSLER, *Secretary*

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Session of Monday, December 27

Monday morning the members of the Society met with the Geological Society of America in the Auditorium of Agricultural Hall of the University of Wisconsin to hear the papers of general geological interest and especially those comprising the Symposium of Precambrian Geology.

At 2 p. m., in the general lecture room of the Soils Building, President Weller called the Society to order in business session in its eighteenth annual meeting. The report of the Council was the first matter of business.

REPORT OF THE COUNCIL

To the Paleontological Society, in eighteenth annual meeting assembled:

The business of the Society has been transacted at sessions of the Council immediately before and after the seventeenth annual meeting at New Haven and by correspondence. A résumé is given in the following reports:

Secretary's Report

To the Council of the Paleontological Society:

The Secretary's report for the year ending December 27, 1926, is as follows:

Meetings.—The Proceedings of the 17th annual meeting, held at New Haven, Connecticut, December 28-30, 1925, have been published in volume 37, number 1, of the Bulletin of the Geological Society of America, pages 225-254.

The Council's proposed nomination for officers for 1927 was mailed to the members in March, 1926, with the announcement of the next meeting of the Society at Madison, Wisconsin, by invitation of the University of Wisconsin and the State Geological Survey.

Following favorable action by the Society concerning the affiliation of the American Association for the Advancement of Science and the Paleontological Society at the 1925 annual meeting, President Weller appointed David White and F. B. Loomis as our representatives on the Council of the former Society.

Membership.—The Society has lost two members by death during the year, Dr. F. H. Knowlton and Dr. Willis T. Lee. Sixteen new members have just been elected and nineteen new nominations await action. The Geological Society of America has just elected seven of our members to fellowship. The total number of members at the end of 1926 is 304.

Publications.—The proceedings and three articles, totaling 85 pages, appearing in the Bulletin of the Geological Society of America have been published during the year.

Respectfully submitted,

R. S. BASSLER,
Secretary.

WASHINGTON, D. C., *December* 27, 1926.

TREASURER'S REPORT

To the Council of the Paleontological Society:

The Treasurer begs to submit the following report of the finances of the Society for the fiscal year ending with December, 1926:

RECEIPTS

Cash on hand December 29, 1925	$968.22	
Membership dues collected for 1926	339.00	
Interest, Connecticut Savings Bank	42.45	
		$1,349.67

EXPENDITURES

Secretary's office:		
Secretary's allowance	$100.00	
Clerical aid	25.00	
Office expenses	77.43	
Treasurer's office:		
Treasurer's allowance	25.00	
Publication:		
Bulletin of the Geological Society of America	82.51	
Miscellaneous:		
Two returned checks	6.00	
Refund of overpayment to L. W. Henry	1.00	
		316.94
		$1,032.73

Very truly yours,

CARL O. DUNBAR,
Treasurer.

NEW HAVEN, CONNECTICUT, *December* 26, 1926.

APPOINTMENT OF AUDITING COMMITTEE

President Weller then appointed Dr. A. F. Foerste and Prof. M. G. Mehl as a committee to audit the Treasurer's accounts.

ELECTION OF OFFICERS AND MEMBERS

The results of the ballot for the election of officers for 1927 and of new members were then announced, as follows:

OFFICERS FOR 1927

President:

W. A. PARKS, Toronto, Ontario

First Vice-President:

P. E. RAYMOND, Cambridge, Mass.

Second Vice-President:

L. W. STEPHENSON, Washington, D. C.

Third Vice-President:

R. C. MOORE, Lawrence, Kans.

Secretary:

R. S. BASSLER, Washington, D. C.

Treasurer:

CARL O. DUNBAR, New Haven, Conn.

Editor:

WALTER GRANGER, *New York City*

NEW MEMBERS FOR 1927

CHARLES I. ALEXANDER, Jr., 35 Williams Street, Princeton, New Jersey.
JOHN R. BALL, 2305 Sherman Avenue, Evanston, Illinois.
CHARLES H. BELANSKI, Nora Springs, Iowa.
W. S. COLE, 614 East Buffalo Street, Ithaca, New York.
ERLING DORF, 4 College Road, Princeton, New Jersey.
IRA EDWARDS, Public Museum, Milwaukee, Wisconsin.
CHARLES S. EVANS, Department of Geology, Princeton University, Princeton, New Jersey.
RICHARD F. FLINT, Department of Geology, Yale University, New Haven, Connecticut.
MARGARET B. FULLER, 14 University Hall, Evanston, Illinois.
PRENTISS D. MOORE, Owensville, Indiana.
GILBERT O. RAASCH, 255 Thirteenth Street, Milwaukee, Wisconsin.
SHARAT K. ROY, Field Museum of Natural History, Chicago, Illinois.
I. P. TOLMACHOFF, Carnegie Museum, Pittsburgh, Pennsylvania.
J. MARVIN WELLER, Geological Survey of Illinois, Urbana, Illinois.
ALEXANDER WETMORE, U. S. National Museum, Washington, D. C.
MONTA E. WING, 1012 Chapin Street, Beloit, Wisconsin.

NEW NOMINATIONS AND ELECTION TO MEMBERSHIP

Nineteen nominations for membership, received after the printing of the official ballot and approval by the Council, were then presented to the Society for action:

GEORGE S. BUCHANAN, Carter Oil Company, Tulsa, Oklahoma, M. S., University of Michigan, 1924. Proposed by E. O. Ulrich and R. S. Bassler.

G. ARTHUR COOPER, 413 Orange Street, New Haven, Connecticut. M. A., Colgate University, 1925. Proposed by Winifred Goldring and Rudolf Ruedemann.

C. F. DEISS, 1014 Cornwell Place, Ann Arbor, Michigan. B. A., Miami University, 1925. Proposed by E. C. Case and R. S. Bassler.

RUSSELL C. HUSSEY, 1420 Geddes Avenue, Ann Arbor, Michigan, Ph. D., University of Michigan, 1925. Assistant Professor of Geology, University of Michigan. Proposed by E. C. Case and E. O. Ulrich.

MAXWELL M. KNECHTEL, Box 20, House of Representatives, Post Office, Washington, D. C. B. A., George Washington University, 1923. Proposed by T. W. Stanton and R. S. Bassler.

J. E. LAMAR, Geological Survey of Illinois, Urbana, Illinois. B. S., University of Chicago, 1920. Proposed by Stuart Weller and R. S. Bassler.

THEODORE A. LINK, 5558 University Avenue, Chicago, Illinois. B. S., University of Chicago. Proposed by Stuart Weller and R. S. Bassler.

ASA L. MATHEWS, 1317 East South Temple Street, Salt Lake City, Utah. M. A., Stanford University, 1924. Assistant Professor of Geology, University of Utah. Proposed by E. O. Ulrich and R. S. Bassler.

W. L. MOREMAN, Texas Christian University, Fort Worth, Texas. M. S., Texas Christian University, 1926. Instructor in Geology. Proposed by W. M. Winton and R. S. Bassler.

MRS. HELEN J. PLUMMER, Amerada Petroleum Corporation, Fort Worth, Texas. M. S., Northwestern University, 1925. Proposed by Stuart Weller and R. S. Bassler.

FREDERICK B. PLUMMER, Amerada Petroleum Corporation, Fort Worth, Texas. Proposed by Stuart Weller and R. S. Bassler.

RUSSELL S. POOR, 807 West Nevada Street, Urbana, Illinois. Ph. D., University of Illinois, 1926. Proposed by Stuart Weller and R. S. Bassler.

H. G. SCHENK, Department of Geology, Leland Stanford Junior University, Stanford, California. Proposed by Bruce L. Clark and R. S. Bassler.

PARIS B. STOCKDALE, 1308 North Main Street, Frankfort, Indiana. Instructor in Geology, Ohio State University. Proposed by J. E. Carman and Stuart Weller.

CHARLES H. SOUTHWORTH, Thedford, Ontario. Proposed by E. O. Ulrich and R. S. Bassler.

HENRY C. STETSON, 128 Brattle Street, Cambridge, Massachusetts. M. A., Harvard University, 1925. Proposed by P. E. Raymond and K. F. Mather.

FRANK M. SWARTZ, Pennsylvania State College, State College, Pennsylvania. Instructor in Geology. Proposed by E. O. Ulrich and R. S. Bassler.

H. R. WANLESS, 241 Natural History Building, University of Illinois, Urbana, Illinois. Ph. D., Princeton, 1923. Instructor in Geology, University of Illinois. Proposed by B. F. Howell and Stuart Weller.

COURTNEY WERNER, 5505 Cates Avenue, St. Louis, Missouri. Assistant Professor of Geology, Washington University. Proposed by E. O. Ulrich and R. S. Bassler.

It was thereupon moved and seconded that the By-Laws be suspended, and by unanimous action the Secretary was instructed to cast the vote of the Society for the election to membership of the nineteen nominees.

There being no further matters of business at present, the Society proceeded in general session to the presentation of papers, with President Weller in the chair.

PRESENTATION OF PAPERS

The first paper was concerned with the paleontology and stratigraphy of an Ordovician formation believed by the author to connect two of the larger standard divisions. Discussion by Messrs. Sardeson and Bassler.

STRATIGRAPHY AND PALEONTOLOGY OF THE DECORAH FORMATION IN NORTHEASTERN IOWA

BY GEORGE MARSHALL KAY

(*Abstract*)

The Decorah has been defined as a shale lying above the Platteville limestone and below the Galena limestone at Decorah, Iowa. To the south and east of the type section, limestone replaces the shale beds; to the north and west, the Galena becomes increasingly shaly. Regardless of the fact that the Decorah becomes less clastic to the south and east, the thickness does not materially diminish, and the shale limits, as occurring at the type locality, remain fairly constant over a wide area. South and east of McGregor, Iowa, where the Decorah outcrop reaches the Mississippi River bluff, the top of the formation, which was originally calcareous, has been replaced irregularly by dolomitization.

Partially as a result of the variations in the interpretations of the Decorah beds, the name Galena limestone refers in southern Minnesota to beds equivalent at the base to the Hull formation of the Trenton group of the East, whereas the "oil rock" at the base of the Galena limestone in northwestern Illinois is as old as the Watertown of the Black River.

The changes in the clastic content of the beds are paralleled by changes in the faunas. The faunas indicate that the Decorah is a formation straddling the Black River-Trenton line. Inasmuch as the Decorah is equivalent in age to beds in the recognized standard classification of the Ordovician, it has no place in that classification; any time significance that it may have is in its being a formation straddling two divisons of the standard section.

In the next paper the author discussed an interesting pathologic development in Ordovician brachiopods which were exhibited.

PATHOLOGIC ORNAMENTATION ON STROPHOMENA INCURVATA SHEPHERD

BY FREDERICK W. SARDESON

(*Abstract*)

Usually an injury by breakage of the growing shell of Strophomena is followed by further shell growth, in which the normal ornamentation of the outer surface is as little as possible distorted or disturbed. That fact is frequently seen in the fossils from the Platteville limestone to the Galena limestone (Trenton) at Saint Paul, Minnesota. In one zone (bed number 5) at this place, however, the restoration from injury is sometimes normal and sometimes not normal or pathologic in ornamentation. The pathologic ornamentation is very unlike the normal and is much more like that of some other associated brachiopod species, especially that of *Clitambonites diversus* (Shaler). The reasons for the pathologic development and its limited occurrence are not explained.

The following speaker presented the results of studies upon the Devonian stratigraphy of Iowa and Missouri:

DEVONIAN OF MISSOURI, ILLINOIS, AND IOWA

BY E. B. BRANSON

(*Abstract*)

The recent tendency to refer all Devonian formations of Iowa and northern Missouri to the Upper Devonian seems to have insufficient paleontologic basis. The Mineola of Missouri bears a fauna which contains none of the typical Upper Devonian species. The Iowa and Missouri formations contain several species not present above the Middle Devonian of Indiana and eastward. The Iowa and Missouri Devonian seas must have been connected with the Indiana seas, as many species are common to both regions.

An account of a visit to the classic localities for Mesozoic and Cenozoic micro-organisms, particularly in France and Germany, was the subject of the next paper, which was illustrated by lantern slides.

COLLECTING MICROFOSSILS IN EUROPE

BY R. S. BASSLER

An unusually well preserved Middle Ordovician starfish was described by the next speaker. Discussion by President Weller and Dr. Sardeson.

FOSSIL STARFISHES IN THE GALENA LIMESTONE OF WISCONSIN

BY RUFUS M. BAGG

(*Abstract*)

This paper deals with the distribution and range of Paleozoic Asteroidea and the description of a small but perfect specimen of Hudsonaster from the Upper Ordovician limestone of Fox River Valley, Wisconsin. The specimen is unusual, in that it reveals the dorsal surface in good preservation and is a rare fossil in the Galena of Wisconsin.

The final paper of the afternoon session was concerned with the operculiform plates of the tabulate corals, formerly considered to be opercula, but interpreted by the speaker as specializations of the epitheca closing the apertures of abandoned corallites. Specimens and lantern slides were used in illustration of the paper, followed by discussion of these curious structures, which the author proposes to call pseudopercula.

PSEUDOPERCULA IN THE TABULATE CORALS

BY CARL O. DUNBAR

At 5.30 p. m. the Society adjourned, meeting in Agricultural Hall at 8 o'clock to hear the presidential address of the retiring President of the Geological Society of America, Prof. A. C. Lawson, on "Folded mountains and isostasy." At 9 o'clock the members participated in the complimentary smoker given by our hosts.

Session of Tuesday, December 28

Tuesday morning, at 9.15, the Society met in general session, with President Weller presiding. The reading of papers was resumed.

The first paper, dealing with a small Triassic dinosaur, was illustrated by lantern slides and discussed by Messrs Romer and Sardeson.

GENUS CŒLOPHYSIS IN THE UPPER TRIASSIC BEDS OF WESTERN TEXAS

BY E. C. CASE

(*Abstract*)

This paper describes the vertebral column, with elongate neural spines, of a small cœlosaurian dinosaur from the Dockum beds of Crosby County, Texas. Other isolated bones, as an imperfect skull, an ilium, and several vertebræ and teeth are associated with this genus, Cœlophysis.

Recent discoveries in Cambrian stratigraphy and the enlargement of the geological column in New Brunswick were described by the author of the next paper.

DISCOVERY OF TWO ADDITIONAL CAMBRIAN FAUNAS IN NEW BRUNSWICK

BY B. F. HOWELL

(*Abstract*)

Two Cambrian faunas, not hitherto found on the mainland of North America, were discovered northeast of Saint John, New Brunswick, during the past summer by Dr. A. O. Hayes and the writer. One is of late Middle or early Upper Paradoxidian age and is characterized by a new form of *Paradoxides*. It is probably somewhat younger than the *Paradoxides abenacus* fauna of New Brunswick. The other, which is known from only a few fossils, appears to be an early Upper Cambrian Olenus fauna, containing an Agnostian trilobite that is very similar to, if not identical with, the common North Atlantic form usually known as *Agnostus pisiformis obesus*.

The account of the interesting geology of the largest of the Fiji Islands, illustrated by the author with charts and lantern slides, followed. Discussion by President Weller.

GEOLOGY OF VITILEVU, FIJI

BY HARRY S. LADD

(*Abstract*)

This paper deals with the stratigraphy and paleontology of Vitilevu, the largest island of the Fiji group.

Two main series of rocks are exposed, each of which contains several fairly distinct rock formations. These may be referred to as the older and the newer series. The former contains plutonic igneous rocks and associated metamorphics. Their relative ages have not been decided with certainty. Some of the metamorphics are slaty and may represent highly altered sediments, but probably most of them were originally volcanic. No fossils were found in the ancient slaty rocks, but the entire older series is thought to be pre-Tertiary.

The newer series, which overlies the older unconformably, contains both sedimentary and volcanic rocks. All of the sediments are locally highly fossiliferous. In a few places this series has been disturbed, but in general the beds show low dips that are remarkably persistent over wide areas. Since the reported "basal conglomerates" appear at a number of horizons and in many cases seem purely local, it is extremely doubtful if this enormously thick newer series can be subdivided properly without the aid of fossils. Locally along the coast a low limestone bench and associated beds of post-Tertiary age are found. With the exception of these beds, the entire newer series is believed to be Tertiary.

Geological evidence indicates that Vitilevu was once a part of a much larger landmass. Topographic and stratigraphic evidence point to heavy faulting along definite lines in parts of the island.

President-elect Parks then gave an account of the Upper Ordovician strata of western Ontario, with lantern slide illustrations. Discussion by Messrs Ulrich and Schuchert.

TRENTON-COLLINGWOOD-UTICA RELATIONSHIPS IN WESTERN ONTARIO

BY WILLIAM A. PARKS

(*Abstract*)

The section on Georgian Bay shows in descending order: Dundas gray shale, Utica gray shale, Collingwood black shale, Trenton limestones. All the formations seem to be strictly conformable. The Dundas and Utica can not be separated lithologically; the line is drawn at the horizon of failure of *Triarthrus*. The Collingwood and Utica can be separated by the sudden change in color of the shale and by the failure of the typical Collingwood trilobite *Ogygites canadensis*. This fossil was formerly considered to limit the downward extension of the Collingwood, but last summer it was found many feet down in the Trenton limestones.

In the Lake Ontario region the Dundas-Utica contact is not revealed, but the Utica shales, with Triarthrus, are dark in color and seem to fade gradually into the gray shales of the Dundas. The Collingwood-Utica contact is seen at Oshawa, but *both* shales are black and the Utica can be differentiated only by the failure of *Ogygites canadensis*.

The term "black Utica shale," therefore, is justified for the Lake Ontario region, but not for the Georgian Bay region, where only the Collingwood member is black. Further, if the Collingwood is to be defined by the presence of *O. canadensis*, it must include not only the black shales with limestone beds, but also many feet of the Upper Trenton. The final paper will include full faunal lists and descriptions of some new species.

At this point the Society voted to meet with the Geological Society of America and hear Professor Chamberlin's address, entitled "Working concepts appropriate to an earth of planetesimal origin."

At 1 o'clock the Society adjourned for luncheon, convening again at 2 p. m., in the auditorium of Agricultural Hall, in joint session with the Geological Society of America for the reading of stratigraphic papers.

STRATIGRAPHIC PAPERS PRESENTED IN JOINT SESSION WITH THE GEOLOGICAL SOCIETY OF AMERICA

DEVONIAN SECTION IN THE SANTA RITA MOUNTAINS OF ARIZONA

BY CLINTON R. STAUFFER

STRATIGRAPHY AND PALEONTOLOGY OF THE PENNSYLVANIAN OF NORTHWESTERN ILLINOIS

BY H. R. WANLESS

CRETACEOUS ROCKS OF THE BOOK CLIFFS IN EASTERN UTAH

BY D. J. FISHER

CRETACEOUS ROCKS OF NORTHERN MINNESOTA

BY IRA S. ALLISON

SIGNIFICANT BREAKS AND OVERLAPS IN THE PENNSYLVANIAN ROCKS OF ILLINOIS

BY T. E. SAVAGE

MONROE DIVISION OF ROCKS IN OHIO

BY J. ERNEST CARMAN

RED BEDS OF ARIZONA, NEW MEXICO, COLORADO, UTAH, AND WYOMING

BY E. B. BRANSON

PALEOZOIC AND PRECAMBRIAN GEOLOGY OF UPPER YUKON VALLEY, ALASKA

BY J. B. MERTIE, JR.

ORDOVICIAN SHALE AND LAVA IN SOUTHEASTERN PENNSYLVANIA

BY GEO. W. STOSE AND A. I. JONAS

TENTATIVE CORRELATION OF THE PERMIAN OF THE SOUTHERN GREAT PLAINS

BY CHARLES N. GOULD AND ROBIN WILLIS

ELEPHAS PRIMIGENIUS BOREUS, HAY, IN ILLINOIS

BY A. R. CROOK

At 4 p. m. the address of the retiring President of the Paleontological Society was delivered in joint session of the two societies.

PALEONTOLOGY AND HUMAN PROGRESS

PRESIDENTIAL ADDRESS BY STUART WELLER

Adjournment until 7 o'clock then occurred, at which time the members met with the Geological Society of America and affiliated societies for the annual dinner.

Session of Wednesday, December 29

At 9.15 a. m. the Society met first in business session, and then proceeded with the reading of papers.

The Auditing Committee reported that the accounts of the Treasurer were correct. Report adopted.

The report of the Special Committee on marking of type specimens was then given by the Chairman, Dr. B. F. Howell; whereupon, at his request, the Society authorized the committee to proceed with its work for another year.

PRESENTATION OF PAPERS

Dr. Ulrich was the first speaker and presented a paper outlining his progress in work upon the Ozarkian faunas, following this with a short discussion of the Black Shale in Michigan. The first paper was discussed by Messrs. Clark, Sardeson, and Schuchert.

GENERAL CHARACTERISTICS AND DISTRIBUTION OF THE OZARKIAN FAUNAS

BY E. O. ULRICH

BLACK SHALE PROBLEM IN MICHIGAN

BY E. O. ULRICH

Next came a description of the occurrence of the peculiar gastropod fauna of Hypseloconus and allied genera in Missouri. This fauna, hitherto known only from the Upper Cambrian Franconia formation of Minnesota, has recently been found near the base of the Davis formation in Missouri, thus affording a valuable tiepoint.

OCCURRENCE OF THE HYPSELOCONUS RECURVUS FAUNA IN MISSOURI

BY JOSIAH BRIDGE

Several species of footprints of large stegocephalians found on rock slabs from the Pennsylvanian system of Ohio were described and illustrated in the following paper. Discussion by Professor Romer.

FOSSIL FOOTPRINTS FROM THE PENNSYLVANIAN SYSTEM OF OHIO

BY J. ERNEST CARMAN

The interesting geology of the island of Eua, in the Tonga group, was then presented, with lantern slide illustrations.

TERRACES OF EUA, TONGA

BY J. EDWARD HOFFMEISTER

(*Abstract*)

The paper is a report of progress of some work on the island of Eua, Tonga, which is located in the Pacific in about latitude 21° 20′ south and longitude 175° west. It consists of a base of bedded volcanic tuff over which is a veneer of limestone. Elevation has occurred, so that at present it stands nearly 1,000 feet above sealevel. The volcanic base is exposed in many places on the high eastern ridge, which runs in a north-south direction for nearly the entire length of the island. As elevation took place a series of well developed terraces were formed, which are most distinct on the eastern, or liku, side of the island. Fossil corals are abundant on the seaward edge of the two lower terraces, which are approximately 100 and 200 feet above sealevel. They are also found in many places on the seaward edge of the 340-foot terrace, the 400-foot terrace, and the 600-foot terrace. The limestone of the higher parts of the island, the inland portions of the terraces, and the cliffs between the terraces is foraminiferal and without any trace of reef-building corals.

From a superficial study of the material found, evidence points to the possibility of the following:

1. That the highest part of the islahd is the oldest.
2. That elevation has taken place with the formation of the terraces in comparatively recent times.
3. That the foraminiferal limestones which make up the high parts of the island and the inland edges of most of the terraces are older than the elevated coral reefs of the seaward edges.
4. That the elevated coral reefs were formed at the time of the formation of the terraces.
5. That Eua is the oldest island of the Tonga group, and that it probably dates back to Tertiary times.

The results of a study of faunal lists of fossil vertebrates from various Red Beds localities to determine their horizons were given by the author of the next paper. Discussion by Professor Case.

VERTEBRATE FAUNAL HORIZONS IN THE TEXAS RED BEDS

BY ALFRED S. ROMER

(*Abstract*)

A study of the localities from which vertebrate remains have been obtained in Texas tends to show that they may be classified as: 1. True Wichita beds, mainly in Archer County, containing a number of forms (*Cricotus*, etcetera) not found in higher levels; 2 and 3. Intermediate beds, mainly in eastern Baylor County, in which a number of Wichita forms have disappeared and new types are appearing; 4. True Clear Fork beds, with *Seymouria* and other new and characteristic forms. Several common forms (as *Dimentrodon*, *Edaphosaurus*, and *Eryops*) are common to all horizons.

Many of the differences recorded are to be regarded as due to migration, rather than evolutionary changes.

The results may be applied to determine the proper correlation of other Red Beds localities of uncertain horizon, such as those in southern Oklahoma.

Glacial drift pebbles in Iowa holding Comanchean fossils were then discussed and conclusions as to their significance were indicated. Discussion by J. B. Reeside, Jr.

COMANCHEAN FOSSILS FROM THE GLACIAL DRIFT OF IOWA

BY A. C. TESTER

(*Abstract*)

Central Kansas marks the northern limit in the Central Interior Plains of the known fossiliferous beds of Comanchean age. Unfossiliferous formations have been traced northward and correlated by the writer on the basis of other criteria. Recently sandstone pebbles and cobbles collected from the glacial drift of Iowa have been examined and their fossil content identified. These pebbles are found largely in the western one-third of the State in Kansan drift, and in a younger, pre-Wisconsin, drift in the northwestern part of Iowa.

The fauna of the pebbles is chiefly of pelecypods and gastropods and is similar to the fauna of Washita age in central Kansas. The writer has made some preliminary studies in the field in an endeavor to locate the source of these pebbles, but so far has been unsuccessful. The importance of these discoveries, incomplete as they are, lies in the following facts:

(1) In the localities where the pebbles were collected the movement of the Kansan ice-sheet was from the north and varied only a few degrees from the meridian.

(2) The friable and non-resistant nature of the pebbles indicates that they would survive only a short distance of transport.

(3) The nearest known or previously suspected fossiliferous beds containing similar fossils is in central Kansas, some 225 miles southwest.

(4) Field and analytical studies of some sandstones of Cretaceous (?) age in western Iowa show a close resemblance to the Comanchean sandstones of Kansas.

Jurassic ichthyosaur remains from Wyoming belonging to a new genus were next described and illustrated.

APATODONOSAURUS, A NEW GENUS OF ICHTHYOSAURS FROM THE JURASSIC OF WYOMING

BY M. G. MEHL

(*Abstract*)

Numerous ichthyosaur remains have been found in the Jurassic of Wyoming—chiefly the southeastern part. For the most part, such remains are identifiable as of the genus *Baptanodon*. A large ichthyosaurian has been

found in the Sundance formation of Freemont County, Wyoming, by the University of Missouri geology field party. This is considerably farther west than other Wyoming finds.

The present specimen differs from other genera in its smaller orbits; the slitlike nares, relatively far from the orbits; the absence of teeth in the lower jaw; and the nearly functionless dentition of the upper jaw. The new genus is to be designated as *Apatodonosaurus*.

An interesting crinoid from the earliest Mississippian of Iowa formed the subject of the final paper on the program.

INTERESTING CRINOID FROM NEAR IOWA CITY

BY A. O. THOMAS

In the absence of the authors, the following papers were read by title:

CONODONT FAUNA FROM THE LOWER MACKENZIE RIVER VALLEY

BY E. M. KINDLE

(*Abstract*)

The character of the Styliolina and other faunal associates of the Conodonts is indicated. The correlation of the conodont and other elements of the black shale fauna, which occur near the top of the lower Mackenzie Paleozoic section, is discussed. Descriptions and illustrations of the Conodonts are given.

MICROFAUNA OF THE UPPERMOST PLIOCENE OR LOWERMOST PLEISTOCENE IN THE LOS ANGELES BASIN, CALIFORNIA

BY A. J. TIEJE

(*Abstract*)

In California it is becoming increasingly clear that the stratigraphical standards of the workers with microfauna and with megafauna are in conflict. Commercial secrecy has had much to do with this lamentable fact. In consequence, the fauna here presented are of interest, since the microforms were found within the shells of "guide" megafossils. The fauna may be discussed in four groups: 1. Minute forms of megafossils; 2. Pelecypods and gastropods, of which the adults are below 5 mm.; 3. Bryozoa; 4. Foraminifera. Each of the groups presents its own special problems, the solution of which (and the consequent use of the microfauna for correlation elsewhere than at the type section) depends on much training, other than that given within the petrographic laboratory.

HITCHCOCK LECTURE ON ICHNOLOGY AND THE DARTMOUTH ICHNOLOGICAL COLLECTION

BY N. M. GRIER

(*Abstract*)

The lecture was deposited with the Department of Geology and Geography, Dartmouth College, by the late C. H. Hitchcock, Professor in the Department

for many years, and is a popular exposition of the subject to which his father, Edward Hitchcock, contributed so extensively, and he to a lesser degree. It will be published chiefly on account of the quaint sidelights it throws on these paleontologists, who were better known to an earlier generation. There follows a list of the objects in the Dartmouth Ichnological Collection as assembled by the son. Many of these are in duplicate and will be available for exchange with other institutions.

NEW MATERIAL FOR THE STUDY OF EVOLUTION: A SERIES OF PRIMITIVE FOSSIL RHINOCEROS SKULLS (TRIGONIAS) FROM THE LOWER OLIGOCENE OF COLORADO

BY WILLIAM K. GREGORY AND HAROLD I. COOK

(*Abstract*)

A series of 25 skulls of the primitive Lower Oligocene rhinoceros *Trigonias*, discovered by the Colorado Museum Expedition in Weld County, Colorado, reveals an unexpectedly wide range of variations in the patterns of the premolar teeth and in skull form. Some specimens have the third premolar submolariform in pattern with two well developed cross-crests, while at the other extreme the same tooth is subpremolariform, with only one well developed cross-crest.

If the two extremes of these specimens were found at different levels without intergrading conditions, they would probably be assigned to different genera.

The skull forms also show wide differences, in some cases possibly of generic rank.

Among the possible explanations of this extraordinarily wide variability are:

(1) The occurrence of several entirely distinct species and genera at one spot and at a single level.

(2) The occurrence of originally distinct forms, together with their hybridized descendants.

Register of the Madison Meeting, 1926

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KOKEN, E. Died November 24, 1912.
NATHORST, Dr. A. C. Died Jan. 20, 1921.
WOODWARD, Dr. H. Died Sept. 6, 1921.

MEMBERS DECEASED

ARMSTRONG, EDWIN J. Died Jan. 21, 1925.
BARRELL, JOSEPH. Died May 4, 1919.
BILLINGS, W. R. Died March 1, 1920.
BOSTWICK, THOMAS A. Died April, 1923.
CALVIN, SAMUEL. Died April 17, 1911.
CLARK, WM. B. Died July 27, 1917.
CLARKE, JOHN M. Died May 29, 1925.
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DERBY, ORVILLE A. Died Nov. 27, 1915.
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FONTAINE, WM. M. Died April 30, 1913.
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BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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PROCEEDINGS OF THE SEVENTH ANNUAL MEETING OF THE MINERALOGICAL SOCIETY OF AMERICA, HELD AT MADISON, WISCONSIN, DECEMBER 27, 28, 29, 1926.

FRANK R. VAN HORN, *Secretary*

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SESSION OF MONDAY AFTERNOON, DECEMBER 27

The Mineralogical Society of America held its seventh annual meeting at the University of Wisconsin, Madison, Wisconsin, in conjunction with the Geological Society of America. At 2 p. m. the meeting was called to order by President Waldemar T. Schaller in Room 206 of Agricultural Hall.

On motion of the Secretary, the reading of the minutes of the last annual meeting was dispensed with, in view of the fact that they have been printed on pages 59-68 of volume 11, number 3, of the *American Mineralogist*.

ELECTION OF OFFICERS AND FELLOWS

The Secretary announced that 154 ballots had unanimously been cast for the officers as nominated by the Council. For Fellow there was a unanimous vote of 71 ballots in the affirmative. All officers and Fellows as nominated were declared elected. The officers for 1927 are the following:

President, AUSTIN F. ROGERS

Stanford University, Calif.

Vice-President, GEORGE L. ENGLISH

Rochester, N. Y.

Secretary, FRANK R. VAN HORN

Case School of Applied Science, Cleveland, Ohio

Treasurer, ALEXANDER H. PHILLIPS

Princeton University, Princeton, N. J.

Editor, WALTER F. HUNT

University of Michigan, Ann Arbor, Mich.

Councilor, 1926-1930, ALEXANDER N. WINCHELL

University of Wisconsin, Madison, Wis.

The Fellow elected follows:

KENNETH K. LANDES, Kansas Geological Survey, Lawrence, Kansas.

The Secretary also announced that the Council, by virtue of authority given by the Constitution, had elected the following Honorary Life Fellows:

Prof. G. FRIEDEL, University of Strassburg, Strassburg, Alsace, France.
Prof. VICTOR GOLDSCHMIDT, University of Heidelberg, Heidelberg, Germany.
Prof. PAUL VON GROTH, University of Munich, Munich, Germany.
Prof. F. L. A. LACROIX, Museum of Natural History, Paris, France.
Prof. L. J. SPENCER, Natural History Museum, South Kensington, London, S. W. 7, England.

REPORT OF THE SECRETARY

The Secretary reports that the roll of the Society now comprises 103 Fellows and 205 members—a loss of 5 Fellows and a gain of 18 members for the year, in spite of the fact that 2 Fellows and 14 members have been dropped from the mailing list for non-payment of dues. Four Fellows—Dr. F. A. Canfield, Colonel W. A. Roebling, Dr. W. L. Uglow, and J. P. Wintringham—have died and a brief account of their careers will be published in the Journal. One member, Charles O. Colton, has also died. In addition to the 308 Fellows and members, there are also 151 subscribers to the *American Mineralogist;* so that there are 459 paid copies of the Journal of the Society mailed monthly. On account of the generous endowment by Colonel Roebling, the financial position of the Society has been very much improved since the last annual meeting. Fifty Fellows, members, and guests attended the meeting. There were thirty-two papers listed for presentation, which exceeds the number for any previous meeting.

REPORT OF THE TREASURER

Owing to the absence of the Treasurer, A. H. Phillips, his report was read by the Secretary, and showed a very favorable financial balance, due largely to the Roebling endowment. On motion, the report was accepted, ordered filed, and an Auditing Committee from non-members of the Council was appointed by the President. This committee, consisting of Dr. L. S. Ramsdell and Dr. A. J. Walcott, later reported to the Secretary that they found the books of the Treasurer correct.

REPORT OF THE EDITOR

The Editor, W. F. Hunt, read his report, which, on motion, was accepted and ordered filed. It was also moved, seconded, and carried that the Editor be highly commended for his work, and that he continue the policy of future development as outlined in his report. During the year the *American Mineralogist* printed fifty-seven leading articles from thirty universities and research bureaus, aggregating 281 pages. However, reports of proceedings of societies, abstracted accounts of new minerals, book reviews, and notes and news brought the total amount of reading matter up to about 350 pages. This is an increase of 100 pages over the output of two years ago and represents the largest volume published to date that was paid for entirely from our own resources.

REPORT OF THE COMMITTEE ON NOMENCLATURE AND CLASSIFICATION OF MINERALS

The report was read by W. T. Schaller, and was from those members residing in Washington, namely, H. S. Washington, E. T. Wherry, and W. F. Foshag. The report was commented upon by E. S. Larsen, A. F. Rogers, and T. L. Walker, who were also members of the committee. It was moved and carried that the report be received and that the committee be continued.

REPORT OF THE COMMITTEE ON PRESERVATION OF TYPE MATERIAL

The report was written by W. F. Foshag and read by W. T. Schaller. It was discussed by A. L. Parsons and A. N. Winchell, who were members of the committee. It was moved and carried to accept the report and continue the committee.

REPORT OF THE COMMITTEE ON HOLDING INTERNATIONAL MINERALOGICAL CONGRESS IN COOPERATION WITH INTERNATIONAL GEOLOGICAL CONGRESSES

The report was written by Charles Palache and read by E. S. Larsen. It was commented upon by T. L. Walker, another member of the committee. It was stated that several members of the Society had met at the International Geological Congress in Madrid and had recommended to the Council of the Congress that a Mineralogical Section be formed. This will be acted upon by the Council of the next Congress.

MEMORIAL BIOGRAPHIES

A memorial sketch of Dr. F. A. Canfield, written by Charles Palache, was read by E. S. Larsen. Another of Colonel W. A. Roebling was written and read by A. H. Phillips. A memorial of Dr. W. L. Uglow was written by R. W. Brock, and a biography of J. P. Wintringham, written by Thomas I. Miller, was read by Frank R. Van Horn. These will be printed in full in the March number of the *American Mineralogist*.

PRESENTATION OF PAPERS

There being no further business, the presentation of scientific papers was taken up as follows, according to program:

NOTES ON THE TRICLINIC PYROXENES

BY A. N. WINCHELL

EUHEDRAL ORTHOCLASE CRYSTALS FROM SIERRA BLANCA, TEXAS

BY JOHN T. LONSDALE AND W. S. ADKINS

At 4 p. m. the Society adjourned to attend the joint session with the Geological Society.

JOINT SESSION WITH GEOLOGICAL SOCIETY OF AMERICA, DECEMBER 27

The Mineralogical Society of America held a joint session with the Geological Society of America at 4 p. m. Monday, December 27, in the Auditorium of Agricultural Hall. President Andrew C. Lawson, of the Geological Society, presided. Dr. Waldemar T. Schaller, of the Mineralogical Society, delivered his presidential address, "Mineral replacements in pegmatites," which will be published in full in the March number of the *American Mineralogist*. During the remainder of the afternoon papers of a mineralogical and petrographical nature were presented, with W. T. Schaller and A. C. Lane in the chair. The joint meeting adjourned at 5.55 p. m.

SESSION OF TUESDAY MORNING, DECEMBER 28

At 9.15 a. m. President Schaller called the meeting to order. The reading of scientific papers then proceeded according to program.

PRESENTATION OF PAPERS

ORIGIN OF TEXAS AND NEW MEXICO POLYHALITE

BY WALDEMAR T. SCHALLER

CAHNITE, A NEW BORO-ARSENATE OF CALCIUM FROM FRANKLIN, NEW JERSEY

BY CHARLES PALACHE AND LYMAN W. LEWIS

CRYSTALLOGRAPHY OF AZURITE FROM TSUMEB, SOUTHWEST AFRICA, AND THE AXIAL RATIO OF AZURITE

BY CHARLES PALACHE AND LYMAN W. LEWIS

OPTICAL PROPERTIES OF ZINCITE

BY HARRY BERMAN

IONITE, A HYDROUS SILICATE OF ALUMINUM

BY VICTOR T. ALLEN

VOLTAITE FROM JEROME, ARIZONA

BY CHARLES A. ANDERSON

SCIENTIFIC VALUATION OF MINERALS

BY GEORGE L. ENGLISH

TREMOLITE CRYSTALS FROM FARADAY TOWNSHIP, ONTARIO

BY T. L. WALKER AND A. L. PARSONS

STROMEYERITE FROM GOWGANDA, ONTARIO

BY T. L. WALKER AND A. L. PARSONS

HEXAHYDRITE FROM OROVILLE, WASHINGTON

BY T. L. WALKER AND A. L. PARSONS

BERYL AND ASSOCIATED MINERALS FROM LYNDOCH TOWNSHIP, RENFREW COUNTY, ONTARIO

BY T. L. WALKER AND A. L. PARSONS

X-RAY DATA ON SOME SULPHIDE MINERALS

BY LEWIS S. RAMSDELL

EVOLUTION OF THE ODD-NUMBERED ELEMENTS

BY W. V. HOWARD

ALTERNATING DEPOSITION OF PYRITE AND MARCASITE

BY W. A. TARR

SULPHIDE INCLUSIONS OF JOPLIN CALCITES

BY W. A. TARR

SPHERULITES IN FOSSIL WOOD

BY J. J. RUNNER

PRIMARY SCAPOLITE IN FOSSIL WOOD

BY J. J. RUNNER

GRUNERITE AND GRUNERITE ROCKS OF THE LAKE SUPERIOR REGION

BY STEPHEN RICHARZ

At 1 p. m. the Society adjourned for lunch.

SESSION OF TUESDAY AFTERNOON, DECEMBER 28

At 2.15 p. m. President Schaller called the meeting to order and the reading of papers continued.

PRESENTATION OF PAPERS

MANUFACTURE OF SYNTHETIC RUBIES AND SAPPHIRES

BY EDWARD H. KRAUS

GEM CUTTING AT IDAR-OBERSTEIN

BY EDWARD H. KRAUS

SAW ATTACHMENT ADAPTING GOLDSCHMIDT'S MODEL CUTTING MACHINE TO THE SAWING OF WOODEN MODELS

BY CHARLES PALACHE AND LYMAN W. LEWIS

KERNITE, A NEW SODIUM BORATE MINERAL

BY WALDEMAR T. SCHALLER

ANAUXITE CRYSTALS FROM TWO WESTERN LOCALITIES

BY AUSTIN F. ROGERS

TABULATION OF THE THIRTY-TWO CRYSTAL CLASSES

BY AUSTIN F. ROGERS

FREDERICK STEARNS COLLECTION OF GEM MINERALS

BY CHESTER B. SLAWSON

Read by title.

ROEMERITE FROM CALIFORNIA

BY R. E. LANDON

GRANITE OF CONWAY, NEW HAMPSHIRE, AND ITS DRUSE MINERALS

BY JOSEPH L. GILLSON

IMMERSION LIQUIDS FOR THE DISPERSION METHOD OF MINERAL DETERMINATION

BY R. C. EMMONS [1]

HOLDENITE, A NEW ARSENATE OF MANGANESE AND ZINC FROM FRANKLIN, NEW JERSEY

BY CHARLES PALACHE AND E. V. SHANNON

[1] Introduced by A. N. Winchell.

VOTE OF THANKS

The last paper was finished at 4.55 p. m., after which it was moved that the thanks of the Society be extended to the local committee, to the authorities of the University of Wisconsin, and to the Wisconsin Geological and Natural History Survey for their kindness and hospitality. This was seconded and unanimously adopted; after which the Society adjourned.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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FOLDED MOUNTAINS AND ISOSTASY [1]

PRESIDENTIAL ADDRESS BY ANDREW C. LAWSON

(Read before the Society December 27, 1926)

I have read many presidential addresses. *Science* publishes something like 52 of them annually. I have also listened to a few. Most of them are characterized by a more or less lucid, and usually very readable, narration of events, discoveries, and theories which mark the progress of the various sciences. In these the audience is presumed to be familiar with the subject-matter of the address, to have first-hand knowledge of the events, to have made the discoveries, and to have formulated the theories which are set forth. In this case the attention of the audience never flags, since it is never strained. The listener amuses himself by running ahead of the speaker, anticipating what he will say next, and keeping himself in the best of humor by finding his anticipations realized. This type of address is thus a literary effort rather than a contribution to the particular science concerned. As literature it can not easily be classed with any of the other literary types which are signalized by labels on library shelves, and it seems to fall into a class of its own. For appreciation it relies on the knowledge of those to whom it is addressed. It is not didactic, since the things asserted are already known. It is not history, since it deals with the present. It is not poetic, though it may be a paraphrase of an epic of human progress. Quotations from the poets are, however, by no means excluded. It is dogmatic, either because it asserts what is not disputed or because the evaluation of evidence in a dispute is wearisome and therefore to be avoided. It is stimulating, in that it records something of intellectual achievement, and it is gratifying to the pride of the listener because he is persuaded that it is his own achievement that is being recorded.

Although in our day it is heard or read only by a few scientific people, this kind of presidential address is destined to hold a high place in the annals of modern civilization; and it is to these annals that the historian will turn, as he seeks to trace the progress of thought, unencumbered by

[1] Manuscript received by the Secretary of the Society December 29, 1926.

the detail which necessarily forms so large a part of the ordinary contribution to science.

There is, however, another kind of presidential address, which is not so entertaining nor so useful. It is indulged in by inconsiderate—I may, indeed, say egotistical—presidents, who seize the occasion to exploit some of their own peculiar ideas, even when they know that these have the flavor of novelty and will, therefore, bore their audience to the limit of endurance. Too indolent to review the present status of their science, they simply dip down into their inner consciousness and produce some hypothesis or theory which nobody ever heard of before, in the vain hope that, by showing how truly it fits the facts, they will get somebody to believe it. They have no regard for the feelings of their audience, which they look upon merely as a scientific jury, rather than a social gathering out for entertainment. This kind of address should, of course, be strictly taboo, to be tolerated only under extenuating circumstances.

These being my sentiments, it is with chagrin that I have to confess to the Society that its presidential address this year will be merely the exposition of an hypothesis. In extenuation I may plead that for the past year I have lived on steamers, and trains, and automobiles and, when not on these, in hotels, and have been far removed from libraries, where I might have found the materials for the compilation of the standard kind of address. Being thus thrown on my own resources, I have been compelled of necessity to draw on and clarify some hazy notions that have come to me, in the course of desultory wondering, about the origin of mountains. These notions were, of course, quite dormant when I needed them, and dipping down into my inner consciousness for them and resurrecting them was not so easy as I had supposed it would be. My subject, however, is as old as the hills, and the views I have to present are, I assure you, not too strongly flavored with novelty for your comfort.

The Rocky Mountains in Alberta and in the northern United States are characterized by the existence of great lowly inclined thrusts. These were first recognized and described by R. G. McConnell[2] in Canadian territory, and have since been the subject of investigation by several geologists in the region south of his classic section to latitude 41 degrees. The thrusts fall into two groups, one extending northwest from the Big Horn Basin, in Wyoming, and the other southeast of the lava fields of eastern Idaho. These great dislocations, the details of which I shall not attempt to quote from the original descriptions, all appear to be overthrusts and are so regarded by the geologists who have studied them.

[2] Report on the geological features of a portion of the Rocky Mountains. Geol. Sur. Canada, Ann. Rept., vol. ii, 1886, pt. D.

Regarding his section, McConnell says[3] that it is characterized in its eastern part by a series of great fractures and thrust-faults in the center by broad sweeping folds, and in the west by folding and crumpling accompanied by the development of cleavage planes and a limited amount of metamorphism. In the eastern faulted portion he identified seven principal faults and six well-defined blocks tilted and shoved over one another eastward, the thrust in all cases coming from the west. "The faulted region is now 25 miles wide, but a rough estimate places its original width at over 50 miles."

Near the international boundary the Lewis thrust has been studied in Montana by Willis[4] and Campbell[5] and in Alberta by McKenzie.[6] The work of these geologists has shown that this great thrust is traceable on its strike for 50 miles in Montana and 85 miles in Alberta, or a total of 135 miles. From its southern known limit to North Kootenay Pass, in Alberta, its trace is at the base of the front ranges; but beyond North Kootenay Pass to Gould Dome, latitude 50 degrees, the trace lies behind the front ranges. The transverse component of shift on the thrust-plane is at least 15 miles, and if Daly's suggestion that the whole of the Clark Range is sessile on this flat fault, then the shift is at least 40 miles. Both Willis and McKenzie agree that the movement on the Lewis fault was an overthrust from the west—that is, the upper western block was shoved over the eastern block. McKenzie speaks of the pressure from the west and says that the present structural features of the region can be explained by compressive stresses acting in an easterly direction. He is troubled, however, by the fact that "the most severe deformation is now exposed in the eastern zones of the disturbed area, or those farthest from the old land to the west, from which the thrust presumably came." He regards this as an anomalous fact and would expect the most severe deformation on the west side of the region affected.

Beyond the southern limit of the Lewis thrust a similar movement was continued southward in a series of thrusts, including the Lombard,[7] Bear Tooth,[8] and Heart Mountain,[9] past the Yellowstone Park, to the base of the mountains on the west side of the Big Horn Basin, in Wyoming. In

[3] Op. cit.

[4] Stratigraphy and structure of the Lewis and Livingstone ranges, Montana. Bull. Geol. Soc. Amer., vol. 13, 1902.

[5] The Glacial National Park. U. S. Geol. Survey, Bull. 600, 1914.

[6] The historical and structural geology of the southernmost Rocky Mountains of Canada. Trans. Roy. Soc. Canada, 3d ser., vol. xvi, sec. iv, 1922.

[7] W. P. Haynes: The Lombard overthrust. Jour. Geol., vol. xxiv, 1916.

[8] W. R. Calvert: Geology of the Upper Stillwater Basin. U. S. Geol. Survey, Bull. 641, 1917.

[9] C. L. Dake: The Heart Mountain overthrust. Jour. Geol., vol. xxvi, 1918.
D. F. Hewett: The Heart Mountain overthrust. Jour. Geol., vol. xxviii, 1920.

every case the apparent overthrust is from the west, and this appearance has generally been accepted as reality; but the origin of the force which shoved the west block over the east and the way in which that force operated have in no case been made clear or even discussed. Hobbs[10] has, indeed, dissented from the notion of overthrust and has recognized the movements as real underthrusts, which he explains as due to the collapse of the arc of the earth in the region to the east, the former basin of the Cretaceous sea. His mechanism is, however, inadequate to produce the effects observed.

The system of apparent overthrusts which thus characterizes the eastern border of the northern Rockies, extending from latitude 50 degrees to latitude 44 degrees 30 minutes, a distance of about 540 miles, although not yet connected with McConnell's section farther north, is a diastrophic feature of extraordinary interest and importance. It is on some of the orogenic problems which that feature suggests that I venture to address you today. Not that I hope to give you a solution of those problems, except in a very tentative sense, but in the belief that the questions of mountain-building and crustal shortening are of deep interest to the Fellows of the Society, and that to focus our attention on any phase of them, even for a brief hour, is to take a step on the road to their solution.

Among the many facts on record concerning this great system of thrusts, there are some which appear to be interrelated and of outstanding significance:

1. We all know that the Rocky Mountains of Alberta and Montana represent a zone of crustal deformation developed at the western side of what had been the Cretaceous epicontinental sea. This sea was characterized by a progressively deepening trough adjacent to the continental margin, which was an inheritance from Paleozoic times. The trough was the analogue of the great Appalachian trough, which throughout Paleozoic time received the sediments derived from the continental area to the southeast of it. The trough on the west side of the Cretaceous sea bears the same orogenic relation to the Laramide Revolution that the Appalachian trough does to the Appalachian Revolution. To signalize its importance in theoretical orogenesis I propose here to call it the Laramide trough. At the end of Cretaceous time, there had accumulated in this trough an enormous thickness of sediments derived from the land to the west. McKenzie[11] states that the aggregate thickness of strata ranging from the pre-Cambrian to the end of the Mesozoic is 40,000 feet, and that during this accumulation there was no pronounced

[10] Mechanics of formation of arcuate mountains. Jour. Geol., vol. xxii, 1914.
[11] Op. cit.

deformation, but only slight oscillation of the region. It was the collapse and uplift of this trough that gave rise to the Rocky Mountains of Alberta and Montana, which thus obey the long-established orogenic law that great ranges are built out of geosynclines laden with excessive sedimentation at continental borders.

2. The collapse of the Laramide trough, though genetically related to the subsidence and sedimentary loading, was a relatively sudden event. It did not proceed gradually, or *pari passu*, with the sinking and filling, but occurred when that process had reached a certain critical limit. The collapse represents a crisis in the local stresses of the earth's crust, whereby they were quickly and almost wholly relieved in one direction, namely, normal to the zone of deformation, or to the elongation of the trough.

3. This relief was effected by a shortening of the arc of the earth indicated by folds and thrusts.

4. The direction of apparent overthrust is toward the basin of excessive sedimentation.

5. The shortening of the arc is not compensated by any gaping of the crust on either side of the zone of deformation.

With these salient facts before us, we may proceed with their discussion, and by that I mean an attempt at the interpretation of their interrelations, their significance for a general theory of orogenesis. None of the facts which I have enumerated is new to the Fellows of this Society and none of them is peculiar to the Rocky Mountains of Alberta and Montana. All of them are true of other great mountain ranges, and, if we can deduce from them a set of conditions consistent with and explanatory of them, we may perhaps formulate a general theory of orogenesis.

I shall begin by assuming that the doctrine of isostasy is a true doctrine; that if, over sufficiently large areas, there be a superficial shift of load, the disturbance of crustal balance caused thereby will be compensated by transfer of mass in depth from the loaded to the unloaded region. The assumption is based on the observational fact that, in regions where we know with certainty that there has been a shift of load, a balanced or compensated condition now prevails. I shall also assume the existence in the earth's crust of a primary, pervasive, tangentially compressive stress. This is an assumption which is commonly made and rarely denied by geologists.

In time antecedent to the close of the Cretaceous an immense load was transferred by erosion from the land area west of the present Rocky Mountains to the floor of the sea on the east, and there was a

concentration of this load in the Laramide trough. This transfer necessitated isostatic compensation. To permit the progressive development of the trough, there was an outflow of rock from beneath it. This flow in depth must have been toward the region that was being unloaded; so that the continental margin supplying the sediments rose progressively as the floor of the trough sank. The deep rock-flow tended to carry the crust above the zone of flowage with it and generated a stress, or pressure, from the east, in addition to the preexistent primary stress. As the sea-floor to the east of the trough was also sinking, though less rapidly, that region would contribute to the rock-flow. Before the close of the Cretaceous this resultant stress appears not to have been effective for deformation, and it was probably within the elastic limits of the crust. Certainly no observable effects can be ascribed to its operation. The crust above the zone of flowage was thick enough and strong enough to withstand the primary tangential compression even when this was reinforced by the drag of the rock current beneath it; but when, by continued subsidence, the layer of brittle rock between the zone of flowage and the weak sediments was sufficiently reduced in thickness, it became suddenly incompetent. This was the crisis of a prolonged process. The limit of competence having been reached, the floor of the trough collapsed horizontally, and with it the contents of the trough. Thus a great orogenic movement was inauguarated, involving shortening of the crust, by thrusting, in the massive rocks below, and folding, followed by thrusting, in the stratified rocks above. An essential feature of the foregoing hypothetical mechanism is that, when this competent rock below the trough is depressed into the zone of flowage, it becomes thereby incompetent and proceeds to flow with the current. In this way the competent rock below the trough becomes thinner and thinner till the critical thickness is reached at the moment of collapse.

But why, it may be fairly asked, should so great a horizontal movement set in just at the time when the trough ceased to sink and the rock-flow from beneath it, therefore, presumably stopped? The answer to this is that the primary tangential stress is the chief force concerned in the collapse. The drag stress reinforced this only so long as it was elastically banked up in the crust after the flow ceased. After the relief of so much of the stress as was due to drag, in the early stages of collapse, the primary stress would continue and would complete the work of deformation. It thus appears that the chief function of the rock current due to isostatic compensation is to create a condition favorable for the operation of the primary stress, to determine a zone of incompetence incapable of withstanding that stress. The potential force of

general compression becomes suddenly kinetic, and a horizontal movement results which involves shortening of the crust. That the primary tangential stress of the earth's crust plays the rôle here assigned to it is proved by the fact that, however great the telescoping of the opposed segments in a zone of collapse—that is, however great the shortening of the arc—there is no gaping of the crust in the rear of that zone on either side. For long distances on either side of a zone of collapse, the local shortening is compensated by an expansion due to the discharge of compressive stress. If the geographical position were determined of a series of points in the crust extending out on either side of a zone of impending collapse and were redetermined after the collapse, it would be found that while the points had all moved toward the new mountain range, the intervals between them had increased, but in diminishing degree as distance from the range increased. The actual shortening of the whole arc of the earth is thus not to be inferred from the amount of closing up observable in any mountain range.

The relief of compressive stress on either side of a zone of mountain-building would be chiefly in one direction—that is, normal to the elongation of the deformation—that elongation having been determined by the configuration of the trough of excessive sedimentation, and that in turn by the contour of the preexistent continent.

When we come to the question of what really happens mechanically in the process of collapse and crustal shortening, it is evident that superficially we have a measure of the shortening in the folding of the strata and in the horizontal shift of the thrusts which pass through the folds; but it is mechanically impossible that the shortening should be limited to this superficial layer of the crust. Below the stratified rocks and above the zone of flowage, there is a layer of massive rock which does not fold. In this layer shortening must be effected by thrusting and telescoping, and this deep shortening can only be accomplished, as I have shown in a previous paper,[12] by underthrust blocks plunging, under concave thrust-planes, into the region of heavy rock, thus causing an elevation of the region affected.

Now, when two segments of the earth's crust are opposed to each other in a zone of weakness and collapse, under a compressive stress adequate to cause telescoping, it may appear a matter of indifference whether we interpret the differential movement as overthrusting or underthrusting. Geologists very generally have regarded the movement as an overthrust, and the Lewis thrust in particular has been so re-

[12] A. C. Lawson: Thrusting and isostasy. Bull. Geol. Soc. Amer., vol. 23, 1922.

garded. It is to be observed, however, that the telescoping of two opposed segments of the crust under the urge of primary compressive stress does not necessarily imply a reciprocal movement of the two segments toward each other. The stress will be relieved and the shortening accomplished if one segment have an acceleration different from that of the other.

In the case of the Rocky Mountains of Alberta and Montana, we have seen that, in addition to the primary stress, which was presumably the same on the two sides of the Laramide trough, there was on the east side a drag of the crust toward the trough, and on the west side a drag away from it, by reason of the rock-flow necessary for isostatic compensation. So long as the crust remained competent and intact, there would, of course, be no real difference in stress on the two sides of the trough; the strain would be uniformly westward; but the moment it became incompetent, there would be a difference in the measure of kinetic energy released on the two sides of the zone of collapse. The advance of the eastern segment at the initial movement of collapse would be more rapid than that of the western segment. The mean plane of stress in the eastern segment would be lower than that of the western segment, and the top of the zone of flowage would probably be somewhat lower, so that the initial conditions would be those of a couple. The profile of the trough would very probably be asymmetric, the deepest part being on the continental side, and the rupture would occur at this its weakest point. Under these general conditions, the first movement of the collapse would be a rupture on which telescoping would proceed. But there are apparently two possibilities with regard to this rupture. It may start either at the top or the bottom of the attenuated portion of the zone of fracture, and the structural outcome of the whole mountain-making process depends on which of these alternatives is chosen. To resolve this question, a brief consideration of the effect of attenuation of the crust on the stresses within it is necessary.

We may imagine an elastic crust devoid of elastic deformation—that is, a crust in which at every depth the horizontal stress is the same as the vertical; but we have no warrant for the supposition that such a condition exists. It is far more probable that, while the vertical stress is fairly constant, the horizontal stress slowly increases. Whether that increase be due to radial shortening of the earth or to volume change caused by the heat of atomic disintegration is immaterial to the present discussion. Within the elastic limits of the material of the crust, the excess of horizontal stress over vertical stress, or stress difference, is

taken up in elastic deformation. So long as the horizontal stress, and therefore the stress difference, continues to increase, the crust is unstable, since it is subject to elastic strain whereby deformation is accomplished. So long as the stress difference is constant, the crust is stable in the sense that there in no farther development of strain.

From this point of view the vertical stress at any given depth may be regarded as a limiting value for the horizontal stress; and since we may readily arrive at approximate values for the vertical stress, we may with advantage consider this particular, though purely hypothetical, case in which the two stresses are equal at any point. The horizontal stress is in this case distributed over a cross-section extending from the surface to the level of compensation, say at a depth of 60 miles, which, according to Jeffreys, is close to but above the level of no strain in a cooling earth. Starting with our initial absence of stress difference, we may suppose the tangential stress to increase. The increase will be always zero at the surface and at the depth of 60 miles.

First, we may consider the increase of tangential stress and therefore of stress difference per unit of cross-section, which is referable to the attenuation of the cross-section. When the trough had been depressed 8 miles and filled with weak sediments, the effective cross-section was reduced to a thickness of 52 miles, and there was a proportionate increase per unit of area of the tangential stress and stress difference, which would, of course, be balanced by resistance to elastic deformation. If we suppose the brittle crust, or zone of fracture, extends down to a depth of 20 miles, this will be reduced by the depression of the trough to a thickness of 12 miles. Eight miles from the bottom will have been incorporated in the zone of flowage and its equivalent in large part transferred to the unloaded continent to maintain isostatic balance. Thus, without the introduction of any new forces of compression, there will be a notable increase of the tangential stress per unit of cross-section by the mere attenuation of the effective crust due to the depression of the trough. This increase would apply, of course, to the region intermediate between zero stress difference at the surface and zero stress difference 60 miles below the surface. It would apply, therefore, to the residual 12 miles of brittle crust, in which the tangential stress would be augmented in the ratio of 60 to 52, or about 15 per cent.

Now, instead of an initial equality of vertical and tangential stress, there may be in the crust, as a result of slow accumulation, an excess of tangential over vertical stress, which excess is balanced by resistance to elastic deformation—that is, the stress difference, however large, is

within the elastic limit. When this is reinforced by the addition due to attenuation of the crust it somewhere exceeds the elastic limit and the structure fails. When this happens, the mechanical procedure of the whole act of collapse depends on whether the attenuated crust breaks at the top or bottom of the zone of fracture; and this question is difficult to answer, owing to our ignorance of the gradient of rock strength in depth. According to Jeffreys,[13]

> "The strength of the rocks of the earth's crust increases inwardly until it becomes several times the strength of the surface rocks; and at some depth, probably of the order of 100 kilometers it commences to decrease, becoming small in comparison with that of the surface rocks at a depth of perhaps about 200 kilometers and finally disappearing about 400 kilometers."

This gives us a gradient in general terms the only specific points on which are 15 tons to the square inch at the surface and zero at 400 kilometers. The curve of stress difference is equally vague, there being only two points known, namely, zero at the surface and zero at a depth of about 60 miles. The depth at which these two curves intersect—that is, the point of initial failure in the zone of fracture—can not, therefore, be precisely determined. There are, however, some general considerations which indicate that the first break will occur at the upper side, or at the bottom of the trough:

(1) Since there is a surface of discontinuity between the elastic crust and the weak sediments which fill the trough, the upper side of the crust will have in some measure the characteristics of a free surface and will, therefore, have a breaking strength lower than that of homogeneous rock at same depth completely confined.

(2) In so far as the brittle crust under increasing horizontal stress behaves as a beam, it is a beam with a deep notch in its upper side, and the axis of the beam is much closer to the bottom of the notch than to the underside of the zone of fracture. In such a beam, under longitudinal compression, the opportunity for the movement necessary for failure is much greater at the notch than on the underside of the beam, which in this case is restrained by gradational continuity with the rock below.

(3) If the accumulating stress overtakes the rock strength at the bottom of the zone of fracture first, the initial yielding will occur in the transition zone between it and the zone of flowage, the zone which is brittle for quickly applied stress and plastic for slowly applied. The curve of increasing stress difference presumably approaches that of rock

[13] The Earth, pp. 128-129.

strength very slowly, almost asymptotically, and failure would be by flowage. This would further attenuate the cross-section of the resistant crust and tend to place the point of failure by rupture higher up. When the break did occur, the sudden redistribution of stress would convert the transition zone into a zone of fracture. If the transition zone were relatively large, the effect would be to locate the initial rupture near the top of the elastic crust.

(4) The trough 8 miles deep is due to bending of the upper crust. There is, therefore, immediately below the trough, a compressive stress due to bending, which will locally reinforce the general stress and tend to precipitate the initial fracture in that region.

(5) Since the initial fracture determines the mechanical behavior of the process of collapse and the consequent structure, we may infer from the known thrusts of folded mountains the nature and place of the initial break.

In the Rocky Mountains the Lewis and other great thrusts dip westward, or away from the region of antecedent excessive sedimentary loading. The same is true of the thrusts in McConnell's section, farther north. The great group of thrusts in eastern Idaho and western Wyoming, of which the Bannock thrust is the type, dip similarly away from the locus of a great basin of excessive sedimentation. The thrusts of the Appalachians dip away from the Appalachian trough, and the thrusts of the Arbuckle and Ouachita Mountains dip away from a still deeper trough, to the collapse of which they owe their existence. The great thrusts of the north of Scotland dip away from all that remains of the Torridonian and Cambrian rocks, and this remnant probably corresponds in position to a trough of maximum sedimentation.

We have in this uniformity of attitude of thrusts the suggestion of an orogenic law which states that in the collapse of a geosyncline the underthrust is from the loaded to the unloaded region. As to the unreality of positive overthrusting I have elsewhere shown,[14] from a theoretical point of view, that in major thrusts the upper block is incapable of propagating for great distances the stress necessary for translation against friction; and this conclusion is sustained by observation.

We now have many published sections of thrusts of great magnitude and low angle, and in all of them the overriding segment is broken, doubled on itself, and traversed by secondary steep thrusts, clearly showing that it is incompetent to withstand the stresses due to friction. We thus have a very strong case for underthrusting as against over-

[14] Thrusting and Isostasy. Bull. Geol. Soc. Amer., vol. 23, 1922.

thrusting, and even against equal or reciprocal over- and underthrusting, in the process of crustal shortening. But the unanswerable argument for underthrusting as the primary mechanism in crustal shortening is that there is no other imaginable way in which the crust can be shortened, to the extent shown in the Rockies, the Appalachians, and other ranges, except by the down plunge of a portion of the crust and its absorption in the subcrustal region.

If, then, in regions of crustal collapse underthrusts with low dip away from the antecedent geosyncline are characteristic and habitual features, then the initial break which determined the attitudes of these faults must itself have the same attitude; and to have that attitude it could only have originated at the top and extended down; for, since the tangential stress must be much greater than the vertical to induce failure, the resultant stress will make a small angle with the horizon; and since this resultant stress is normal to the direction of maximum tension, the initial rupture will have the same low angle. But as the rupture proceeds, however quickly, the direction of the tangential stress, and therefore the direction of maximum tension, will change and the rupture will follow a curving course. If it start at the top, it will be flat there and steepen toward the bottom of the zone of fracture. If it start at the bottom, it will be flat there and steep at the top of the zone. Now, since the known major thrusts of folded mountains emerge at a low angle, it follows that they must have started at the top and torn downward; and since the initial thrust presumably has the same attitude as the observable thrusts, it also started at the top.

These general considerations are the justification for the assumption, which I have adopted, that the collapse begins by a shear rupture at the top of the attenuated crust. The tear, once started, of course determines a sudden concentration of stress on the still untorn part, and so extends downward, not only severing the brittle crust, but also, by reason of the rapidity of redistribution of stress, proceeding far down into the zone of flowage for more slowly applied stresses, where the discontinuity would, however, soon disappear. The rupture would be concave downward, and under this concave fault the underthrust would proceed slowly, culminating in the down plunge of the stub end of the crust into the zone of flowage.

The initial rupture and underthrust would determine the course of all subsequent movements concerned in the process of crustal shortening and mountain-building. If we try to visualize the further progress of events in the development of the Rocky Mountains, the eastern segment of the crust would continue to be relatively active, because the

eastward strain of the western segment would be opposed by the steep portion of the curved thrust surface, under which the eastern segment continued its slow downward plunge. The stress in the western segment would therefore be relieved chiefly by an eastward migration of the thrust and only to a limited extent by positive overthrusting. This migration of the fault would be permitted by the slackening of stress in the eastern segment as its underthrust or downthrust proceeded. The downthrust mass would, of course, merge into the zone of flowage and there be redistributed; but, being lighter than the rocks of that zone, would result in uplift in order to maintain isostatic balance.

The shortening of the brittle crust under a geosyncline filled with sediments, by the mechanism of underthrust into the zone of flowage, obviously provides the conditions necessary for the compression, acute folding, and thrusting of the contents of the trough. The doubling up and telescoping of the strata are the superficial manifestations and a consequence of the shortening in depth.

The shortening of the crust by the mechanism here outlined of course means a concentration of mass in the zone of deformation, and the excess of mass is proportionate to the measure of shortening; but, by reason of the principle of isostasy, this excess of mass can not endure; it can not even exist. The concentration of mass is, therefore, only a tendency which is counteracted by the distribution of the excess under gravity into neighboring regions. The concentration takes place both at the top and bottom of the deformed belt. At the top the stratified rocks are crowded together in folds of great amplitude, and these may be closely appressed. The bottoms of the synclines can not be lower than the bottom of the stratified rocks before folding set in, since under the general condition of compression there can be no accommodation downward for folding. The surface of the deformed region is, therefore, raised by the amount of the amplitude of the appressed folds. The difference of elevation due to this cause affords a measure of the added mass; but to whatever extent this additional mass disturbs the isostatic equilibrium it tends to depress the region on which it has been imposed, so that the net elevation due to folding may be small.[15]

At the bottom of the deformed zone the addition of mass by underthrusting is much greater than at the top. Here superficial rocks of low specific gravity displace heavier rocks, and the effect is to increase the isostatic buoyancy of the zone, so that the newly formed and forming mountains receive a notable uplift. These downthrust lighter rocks

[15] Cf. H. F. Reid: Isostasy and earth movements. Bull. Geol. Soc. Amer., vol. 23, 1922.

will, however, be incorporated into the zone of flowage and be distributed, as promptly as inertia and viscosity will permit, so as to obviate any acute disturbance of isostatic balance. The excess of added mass over and above that required to float the growing mountain range, together with the displaced heavier rocks, will flow into the regions flanking the zone of acute deformation on either side. This insertion will lift those regions in a degree diminishing with distance from the mountains. The adjustment will go on until deformation ceases and until the new mountains are in balance with the flanking regions. Thus we may explain the high plains sloping up to the base of the mountains.

Moreover, since, under the hypothesis here advanced, the excess mass which is concentrated in the zone of collapse comes from the flanking regions on either side by elastic expansion, the resulting mountains and their flanking regions together constitute a closed system the balance of which, with the rest of the earth, is not disturbed. It is assumed that the flanking region on either side is limited in width to a few hundred miles, that the mass contributed to the zone of collapse is the effective equivalent of a wedge tapering from a maximum at the mountains to nothing on its remote side, and that the compensating mass in depth is the effective equivalent of a similar wedge; so that as crustal shortening proceeds isostatic balance is maintained throughout the process and within the system.

When the process of crustal shortening is complete it may be presumed that the residual tangential compressive stress has been equalized on the two sides of the zone of collapse. On the east the stress has been relieved by downthrust, and on the west by the eastward migration of the thrust-plane. At the border of the zone of deformation, on each side, the undeformed crust has closed in on that zone an equal amount. If, to be concrete, the total shortening of the crust were, say, 20 miles, each segment has closed in 10 miles. This 10-mile closure means an elongation of a broad zone on either side due to expansion under diminishing tangential stress; so that, as has been already stated, there is no real shortening of the arc of the earth as a whole.

Just as the superficial shortening indicated by the folding of strata necessitates the recognition of shortening in the zone of fracture, so there must be a still deeper shortening, diminishing, however, with depth. There is probably no shortening below the zone of compensation or, at least, below the level of no strain. We may conveniently assume, then, that the shortening at a depth of 60 miles is zero. If the amount of shortening at the surface is 20 miles, then the prism eliminated is a wedge pointed down having a cross-section of 600 square

miles. If we assume that the zone of fracture is 20 miles thick, the greater part of the wedge is in that zone. In the shortening process a mass equal to one-half of this wedge comes from each side of the zone of collapse and is added to the zone of flowage, there to be distributed so as to maintain or restore equilibrium. The mass thus derived from the flanking regions is due wholly to diminution of density or expansion of volume, and it is effectively the excess of volume which is produced by that expansion which is eliminated from the arc of the crust to the increase of its thickness. In the brittle crust, throughout the process of transfer of load the stress diminishes chiefly in the horizontal direction normal to the zone of collapse; but there is also a relaxation of the vertical stress due to the change in density by expansion, whereby the weight of the unit column to the surface is reduced, while the stress in the horizontal direction parallel to the zone of collapse remains constant. The expansion is effected wholly by horizontal elongation toward the zone of collapse, and this elastic deformation involves a shortening of the vertical dimension of the deformed mass and therefore a lowering of the surface.

This withdrawal of mass from the flanks of the zone of collapse by expansion and elastic deformation is a shift of load, and the region will rise by compensation, the amount of uplift depending on the width over which the negative load is distributed. Suppose, for purposes of illustration and trial, that the width is 600 miles, and that the horizontal expansion varies from nothing at the far side of this area to a maximum at the zone of collapse, then the load removed will be equivalent to a wedge of rock $\frac{300}{600} \times 2 = 1$ mile thick at the border of the mountains, tapering to nothing 600 miles away. The uplift due to this loss of load will have a similar profile, but be somewhat less in amount, depending upon the densities of the more superficial and deeper rocks.

But this uplift is counteracted in part by the lowering of the surface, due to diminution of the vertical dimensions of the crust under lessening horizontal stress. This subsidence will also be a maximum near the zone of collapse and a minimum at the far side of the 600-mile-wide belt. If we had to deal with elastic deformation only, then this subsidence would approximately neutralize the uplift due to isostatic compensation; but cubic expansion is also involved and the amount of subsidence is a resultant of a complicated process of adjustment.

One of the most interesting of the many geological implications of the doctrine of isostasy is the rejuvenation of mountain ranges and their persistence as features of relief under prolonged erosion. In pro-

portion as a range is degraded, the loss of mass is compensated by the insertion beneath it of other rocks derived from neighboring regions. This transfer takes place in the zone of flowage, where the rocks are presumably heavier than those exposed to erosion at the surface. The thickness of the layer inserted would, therefore, be less than that of the layer removed; so that the rise of the mountain zone would be somewhat less than the measure of its denudation. Owing to this tendency to maintain isostatic balance, a range may yield sediments to neighboring or distant basins of accumulation which are several times the volume of the range above the baselevel of erosion at its maximum altitude. If to neighboring basins—that is, on the lower flanks of the range—these will sink by reason of the load received, as well as by withdrawal of rock in depth to compensate for the diminished mass of the range; if to distant basins, the flanks will still be depressed by loss of rock in depth to the mountains.

Thus the Rocky Mountains had no sooner been brought into equilibrium with the adjoining regions by the outflow of the excess of mass created by crustal shortening than, in consequence of erosion, the deep rock current was reversed. The mountain range began to rise and the flanks to sink, thus creating a shear zone at the border of the two regions. As this shear developed and became effective for rupture, new structures would be added to the range; but the progress of the shear might be interrupted if the flanks became subject to extensive and deep degradation.

It remains to be added that the process here sketched can not go on forever. The rise of the mountain area to maintain equilibrium is at a less rapid rate than the reduction of its surface by erosion. There is, therefore, a steady net lowering of the surface which will eventually bring it to the baselevel of erosion. The mechanism runs down and stops when the erosional process becomes impotent for the further shift of load.

The Great Laramide trough seems to have ended to the south in what is now the Big Horn Basin. Indeed, there is a suggestion in this relationship that the configuration of the end of the trough determined the shape of the basin, surrounded, as it is, on the east and south by the Big Horn Mountains and on the southwest by mildly folded Cretaceous strata. South of the present Big Horn Mountains there appears to have been a great gulf in the Cretaceous sea which extended westward into eastern Idaho and southward across eastern Utah. The western side of this gulf at the north seems to have received a large share of the erosional waste of the continent to the west. It was probably the site

of a great Cretaceous delta, the floor of which subsided under accumulating load. A basin was developed analogous to the Laramide trough, which was, like the latter, an inheritance from an earlier condition, since it contains notable thickness of Jurassic, Triassic, and Carboniferous strata beneath the Cretaceous deposits. For convenience of reference, I shall call it the Wyomid Basin, since it is traversed by the Wyoming-Idaho State line. In this basin there had accumulated up to the end of the Cretaceous not less than 35,000 feet of strata. The Cretaceous section measures 20,000 feet, according to W. C. Knight, and this is probably an underestimate.

The collapse of this deeply filled basin gave rise to two mountain zones, one parallel to its western border, the Idaho-Wyoming chain, comprising several ranges, and the other, the Uinta Range, on its south side, with a trend at right angles to the first. Mansfield[16] has given us an excellent summary of the structural features of these ranges, together with a brief discussion of various hypotheses explanatory of them and references to the writings of geologists who have studied them. In the Idaho-Wyoming chain the rocks are folded and traversed by a system of great thrusts, of which the more notable are the Bannock, the Absaroka, and the Darby. The dip of all the thrust-planes is west or southwest—that is, away from the area of antecedent excessive sedimentation. The minimum measure of shortening by both folding and thrusting is over 20 miles, or over 52 per cent of the original width of the belt.

Here again, as in the case of the Laramide trough, the collapse was not a gradual process, *pari passu* with the loading of the basin, but was a sudden event, deferred till that loading had created a critical condition locally in the strength of the depressed portion of the crust. The lower part of the brittle crust was swept away, as it sank into the zone of flowage to compensate the adjoining continental margin for its growing deficiency of mass. The crustal shortening, measured at the present surface in terms of folds and thrusts, could have been possible below the zone of folding and above the zone of flowage only by underthrust. The attitude of the recognized thrust-planes indicates very clearly the direction of that underthrust. The underthrust segment of the crust must have become in depth a downthrust, to be disposed of in the zone of flowage in accordance with the necessities of equilibrium. The force chiefly concerned in the collapse of the Wyomid Basin could only

[16] Structure of the Rocky Mountains in Idaho and Montana. Bull. Geol. Soc. Amer., vol. 34, 1923.

have been the primary compressive stress of the earth's crust, which, while ordinarily within the elastic limits of the latter, becomes, by the release of kinetic energy, effective for acute deformation and shortening in zones which have been weakened by depression under excessive load.

The shortening of the crust effected by the folding and thrusting of the Idaho-Wyoming mountains relieved the primary compressive stress of the region in an east-west direction only. The north-south stress was relieved by a second collapse, which culminated in the great east-west asymmetric fold and thrust of the Uinta Mountains. The steep apparent overthrust on the north side of this range is probably significant of greater underthrusting in depth, whereby more shortening was effected than is evident at the surface. The shortening by folding in the Uinta Range is probably not more than 5 per cent of the original width of the deformed belt. The amount of shortening by thrusting is not at present known.

The appeal here made to elasticity of rock to account for the shortening of the crust assumes, of course, the adequacy of that force to do the work ascribed to it, and on this assumption a word is in order. We may conveniently limit our consideration to the behavior of the zone of fracture. In this zone rock may have a crushing strength of 100 tons to the square inch, according to Adam's experiments.[17] This means that the rock is capable of sustaining a stress difference of 100 tons to the square inch before breaking, the stress up to that point being taken up by elastic deformation and reduction of volume. Taking the modulus of elasticity of granite as 9,000,000, the elongation of the crust in one direction on relief of a stress difference of 100 tons would be about 2.33 per cent by elastic deformation alone. By volume change alone, without deformation, the linear expansion would be about 1.4 per cent on relief of the same stress difference.[18] When both volume change and deformation occur together, I know of no means of estimating the total linear elongation; but 3 per cent seems to be a safe figure. On this basis, if the expansion were uniform, there would be, as a result of the relief afforded by collapse, an elongation of 10 miles on one side of the zone of deformation in 333 miles of crust. But, since it has been assumed that the expansion is at a maximum close to the point of relief and is a vanishing quantity on the far side of the belt affected, that belt must have a width of 666 miles to account for 10 miles of shortening on one side of the zone of collapse. It thus appears that the mechanism sup-

[17] F. D. Adams: Jour. Geol., vol. xx, 1912.

[18] Taking the modulus for granite determined by Adams and Coker. Am. Jour. Sci., vol. 22, 1906.

plied by elasticity is competent to account for a shortening of 20 miles, if the expansion due to the relief of a stress difference of 100 tons to the square inch be distributed over a belt 666 miles wide on each side of a collapsing geosyncline. For a shortening of greater magnitude the width of the belt affected may be larger.

The diminution of thickness of the brittle crust under horizontal elastic elongation would be about 2.27 per cent where the expansion was a maximum, near the zone of collapse, and nothing on the far side of the 666-mile belt. This would correspond to a wedge .454 mile thick near the mountains and tapering to nothing 666 miles away. If the thinning by elastic deformation of the 40 miles below the brittle crust were the same in amount, the total lowering of the surface from this cause would be .9 mile at the inside of the expanding belt and nothing at the outer side. The cross-sectional area between the two surfaces would be $\frac{666\times.9}{2} = 299$ square miles, corresponding to half the wedge eliminated from the crust in the zone of collapse. The purpose of the figures is, of course, not to prove anything, but simply to give concreteness and plausibility to the mechanism suggested. The lowering of the surface which the thinning of the crust tends to bring about is, as has been stated, counteracted by the uplift due to compensation necessitated by the removal of load in the thinning process.

An interesting consequence of the shortening of the crust by elastic expansion is that, since compressive stress is small or absent at the surface, the elongation of the deeper layers, as stress there is relieved, necessitates a tensional stress in the superficial layers. In the case of shortening of 10 miles on each side of a zone of collapse the migration of the surface toward the region of collapse can only be effected by distension of approximately that amount. This would involve normal faulting, with an aggregate horizontal shift of about 10 miles in the 666 miles which we have arrived at as the width of the flanking belt. This would, of course, be distributed in many faults and would be the equivalent, on the average, of one fault of, say, 60 degrees dip, with a dip slip of 160 feet and a horizontal shift of 80 feet, or several faults with an aggregate dip slip of 160 feet and an aggregate shift of 80 feet, per mile. These faults would be more numerous near the zone of collapse than at the outer side of the belt. In regard to the region to the east of the Rocky Mountains, this amount of normal faulting is probably not in excess of that actually affecting that region.

A brief summary of the views here presented may be of service to those who do not care to read a paper until they first know what it is all about. If we start with a high continental margin bordering a

shallow sea, the two regions being in isostatic balance, the degradation of the land determines a negative load, which will be compensated by the transfer of mass from beneath the sea to beneath the land. The latter will accordingly rise and the sea-floor will be depressed. The depression will inaugurate a geosyncline, which thus becomes a trap for sediments and so tends to fill up. The geosyncline will continue to develop partly by reason of the load delivered to it, but chiefly by reason of the withdrawal of mass from below it to compensate the growing deficiency of mass in the continental area. The rate of compensation is fitful, or periodic, due to the fact that when the geosyncline is full the waste from the land is carried elsewhere, and it receives no additional load until it suffers renewed depression caused by the increase of negative load on the continent. The geosynclinal depression is a bending down of the crust, and the lower part of the zone of fracture is, therefore, depressed into the zone of flowage and assumes the physical characteristics of that zone. There is thus a thinning of the zone of fracture between the bottom of the trough and the zone of flowage.

In the Rocky Mountain region the geosyncline, which had been developing there throughout Paleozoic and Mesozoic time, had by the end of the Cretaceous attained a depth of about 8 miles and had been filled with sediments much weaker than the crust upon which they reposed. The zone of fracture had thus been reduced in thickness by 8 miles. If we suppose the original thickness to have been 20 miles, it was reduced to 12 miles. The growing attenuation of the brittle portion of the crust increased the tangential stress per unit of area of its cross-section. The stress difference thus approached the strength of the rock and the critical stage was reached by a depression of 8 miles. The rock was then unable to withstand the stress difference and the structure failed. The initial movement of failure was a shear rupture starting at the bottom of the geosyncline and traversing the crust on a curving course, concave downward. Beneath this curving fault the eastern segment of the crust was underthrust and eventually downthrust into the zone of flowage. A great process of horizontal collapse was thus inaugurated, whereby the crust was shortened and the sediments in the geosyncline acutely folded. The relief afforded by the collapse permitted the discharge of horizontal stress for some hundreds of miles on either side, so that the crust expanded toward the break. On the east side the expansion was taken up by downplunge and on the west by eastward migration of the curved thrust.

For an assumed shortening of 20 miles an elastic expansion of a belt 666 miles wide on each side of the zone of collapse would suffice, the

expansion varying from a maximum at the inner side of the belt to nothing at the outer side. The outer limits of the flanking belts do not approach each other. They mark the borders of a closed isostatic system, and all the shortening due both to collapse and strain is effected within the system. The local excess of mass in the zone of flowage due to downplunge is distributed to maintain balance, so that both the folded mountains and the flanking regions are elevated, the latter in diminishing degree away from the mountains. Besides this, there are two other adjustments of the flanking surface: a lowering of the surface due to the diminution of the thickness of the crust, caused by attenuation normal to the direction of crustal elongation, and a rising of the surface due to compensation for diminished density.

In the early stages of this mountain-building process the rock-flow in depth to maintain balance is away from the mountains to the flanks; but as the mountains come under the sway of erosion, their loss of load determines a reversal of the direction of flow, and there is established a steady tendency for the mountains to rise and the flanks to subside. In general the mechanism here outlined in a hypothetical spirit affords a satisfactory explanation for the localization of crustal deformation under the general theory of slowly increasing tangential compression, while it obviates the necessity of inferring from folded mountains a large amount of radial shrinkage. My main purpose is to call attention to the importance of elastic expansion as a force in orogenesis.

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PALEONTOLOGY AND HUMAN RELATIONS[1]

PRESIDENTIAL ADDRESS BY STUART WELLER

(Read before the Paleontological Society December 28, 1926)

It is my purpose today to deviate somewhat from the usual custom of speakers on occasions like the present. I shall attempt to present to you neither the results of research in which I have been engaged, nor an outline of the progress of the science which I represent, during the past year. I shall attempt, rather, to outline briefly a train of thought in which I have been interested for many years and which may have a somewhat more general interest than the presentation of a more technical subject.

Doubtless there is no topic which possesses a wider interest for members of the human race than the topic of man himself, and I have found during my thirty years of teaching paleontology that students of this subject are always deeply interested in any contacts which can be suggested or established between the problems associated with the extinct life of the earth and human affairs.

To the average person the word fossil conveys the impression of something dead, something so absolutely dead as to be beyond all possibility of resuscitation. It carries the impression of something that is unchangeable. The epithet "old fossil," when applied to a man, signifies the superlative of conservatism, a man so devoid of the possibility of change that he is mentally dead.

From a study of the fossil trilobite and brachiopod remains in the ancient strata of the earth's crust to a consideration of human relations in the year 1926 A. D. may seem to be a path of interminable length, but notwithstanding the remoteness of the time when the Cambrian faunas represented the life of our planet, or of the still vaster remoteness of the earliest ancestors of the Cambrian trilobites and their associates, there has been a continuity of life on the globe. Man himself has unquestionably arisen from a more lowly and less specialized

[1] Manuscript received by the Secretary of the Society December 29, 1926.

ancestor than himself; this ancestor in turn looks back for his origin to still simpler forebears, and so on back and back into the long past periods of earth history.

It is the task of the paleontologist to carry on researches concerned with the extinct life of the earth, but the continuity of this extinct life with the contemporaneous life, including man himself, seems to warrant making the attempt to find some lesson from the past for the guidance of the present. The word "history" as commonly conceived refers to human history alone; but, because of the unbroken continuity of events, the roots of all human history must lie far back in the prehuman periods. Just as the consideration of the morphological evolution of man leads us back into prehuman periods, so the evolution of man's social relations originates in the remote periods of the past, long ages before the appearance of man himself. These relations of the present with the remote past are too much overlooked by students of human history, every one of whom would be the gainer were he to possess at least some understanding of geology and paleontology. H. G. Welles seems to be the only historian, in the commonly accepted sense of the term, who has begun his story of humanity with a consideration of the prehuman inhabitants of our earth, and although his treatment of this phase of the subject is brief and somewhat distorted, it shows an appreciation on his part of the desirability of linking the events of the really ancient history of our planet with the modern or human phases of the subject.

The materials with which the paleontologist must deal are the dead, unchangeable fossils, dug up from the rocks of the earth's crust, but the problems which arise from the study of these materials are far from dead, being filled with living interest and giving real vitality to the whole field of historical geology. These now defunct fossils were once living, growing organisms, which were associated together in innumerable faunas, which lived in all portions of our earth, which followed one another in almost endless succession from the earliest recorded period of geological history to the present time, and which were adapted to all sorts of environmental conditions on the land and in the sea.

This inconceivably vast succession of life assemblages which has inhabited the earth has left, of course, only a meager record, and of the record which is preserved in the rocks only a small part is now or ever will be available to the paleontologist for study. This record, however, is a record of accomplishment. All of these prehuman inhabitants of the earth have been subject to the same laws of evolution, in all its

aspects, that are directing the life of the present, and while the paleontological data are not subject to direct experimental study, natural experimentation has been in operation on a vast scale, some of the results of which are available for consideration.

It is not my purpose in this paper to discuss the bearing of these paleontological records on the morphological evolution of man, but rather some of its bearings on human relations. In all probability the human species will undergo little or no essential morphological change in the centuries and millenniums to come, while he is a resident on the earth. He may suffer the loss of certain minor parts through disuse, but in all probability the man of the year 1,000,000 or of 10,000,000 A. D. will be essentially what he is today as regards his physical form and organization. Man has become the master of his environment, and because of this he is able to adapt himself individually to almost every condition on the face of the land and of the sea, and with his mechanical devices he even penetrates the air itself and the depths of the ocean.

Notwithstanding man's control over his environment, his social organization is far from complete; it is, in fact, so entirely out of adjustment that warfare and strife between all sorts of groups is continual. It must be recognized that, geologically speaking, man is in his infancy. He has been a resident of the earth for perhaps one-half million of years—a short time geologically—and for 475,000 or more years of this time he led an existence but little different from that of his other animal associates. The gradual attainment of environmental control doubtless was the real reason for his recent rapid advancement, and it has been only a few thousand years since he began to live together in large communities, where the necessity for elaborate social organization has become imperative. The human generation is a period of twenty-five or thirty years; about three or four generations in one century, thirty or forty in a thousand years. Our ancestors had scarcely emerged from the condition of savagery two thousand years ago, less than one hundred generations. When we look into the future our expected existence is measured, not by scores or hundreds of generations, but by many thousands, and during all of this period the laws of evolution will continue to act and our social organization will become more and more perfected.

The paleontological record is a vast sociological as well as a morphological record. The organisms of the past have lived in faunal assemblages comparable in a way with the groups of complex human societies of which we are a part. This life record is the exemplification of a great

sociological experiment, the consideration of which should be full of suggestion to the student of present human social relations. The parallels between the history of the extinct fossil faunas of the paleontologist and the human social groups are many. Numerous provincial faunas are recognized, more or less completely isolated from other contemporaneous faunal groups, by reason of a lack of means of intercommunication. Certain human societies likewise are, or have been, conspicuously provincial in character, and this provincialism is due to the same cause, namely, a lack of the means of communication. A mountain range or a great river, in the past, have been effective barriers which have prevented the intermingling of groups of peoples. These groups may have originated from the same stock, but, lacking contacts one with the other, they have developed differently and finally have come to exhibit conspicuous differences.

Most of the organisms whose life records have been preserved in the rock strata were creatures whose existence was spent in an aquatic environment, because the most of our fossil-bearing rocks are consolidated sediments which were laid down in water. Furthermore, by far the most of these aquatic sediments, with their inclosed remains of once living animals, are marine in their origin. Likewise most, if not all, of our marine paleontologic record is of comparatively shallow-water organisms. The pathways along which means of communication have been established for such shallow-water marine life are wholly different from the lines of communication suitable for land-living creatures such as men, but the relation of lines of communication to the faunal or social evolution of these creatures themselves is the same. Among the creatures of the past, at times when environmental conditions approached uniformity throughout large portions of the earth and when pathways of communication were relatively open and continuous, a tendency toward the development of widespread, more or less uniform faunal assemblages existed, although at no time did such conditions become sufficiently perfected or continue unbrokenly for long enough time to permit the establishment of a truly worldwide, cosmopolitan fauna. The Silurian faunas of North America and northern Europe possess many common characteristics, showing beyond question that some pathway of shallow marine water communication existed during that period which permitted the creatures inhabiting these widely separated seas to intermigrate from one region to the other. During a portion of Mississippian time the marine faunas of central North America and those of northwestern Europe possess much in common, to account for which

some pathway of intercommunication must be assumed to have been in existence. Many other examples of close similarity between extinct contemporaneous marine faunas, in widely separated portions of the earth, are well known, and the existence of such similarities is uniformly accepted by paleontologists as evidence for the existence of some pathway of communication between these distant localities.

Likewise the animals and plants which have lived on the land have shown relationships over widely separated geographic areas at certain periods. During Upper Miocene time the land Mammalian faunas of North America and Europe are known to have included so many closely related forms that the only possible explanation of the situation is the assumption of the existence of a so-called "land bridge" over which these creatures could pass. As the existence of such a line of communication could only have been in the far north, we are forced to the conclusion that the climatic conditions of the period were much different from those which now obtain. At this time the primitive horses seem to have migrated from America to Europe, while the primitive elephant-like mastodons found their way from Europe into America. Many other mammalian types, including members of the rhinoceras and tapir families, are also common to the two continents at this time.

During Carboniferous time the plant life of North America and Europe possessed many common characteristics. Many of the same genera and the same species are recognized in the fossil floras of these widely separated regions, and they could only have had such geographic distribution with lines of land communication somewhere between the two continents.

Some periods in geologic history show notable provincialism in the development of life on the earth. The northern and southern American continents were essentially isolated, so far as their land life was concerned, during much of Tertiary time, known as the age of Mammals, so that in South America, especially, a notable provincial land fauna developed. About the beginning of Tertiary time there seems to have been a limited connection between the two continents, following which isolation of the southern continent is believed to have been complete until Miocene time, when a few of the peculiar southern types began to filter through into the more northern continent.

The most isolated continental area of the present time is Australia, and because it has lacked any land connections with other continents for so long a time, it has come to be inhabited by a most peculiar, provincial land fauna. If means of communication between Australia and its

neighboring continents had existed, its Marsupial fauna undoubtedly would have been much modified and perhaps completely exterminated by the more advanced Mammalian types.

During Devonian time a number of distinct marine faunal provinces are known to have existed within the limits of the North American continent, each one inhabited by an assemblage of creatures distinctly different from those in another province not greatly removed geographically, but separated, nevertheless, by a barrier which was insurmountable to the creatures whose fossil remains we now dig out of the rocks. With changes in the course and positions of the strandlines of this period, notable changes in the distribution of the faunas themselves came about. The story of the faunal changes and migration of this ancient Devonian life, read from the paleontological records in the sedimentary rocks, is as fascinating as the story of the migrations of human races. Indeed, the analogies between the human record and the paleontological record are really amazing.

The Cuboides fauna of late Devonian time appeared suddenly in the paleontological record of the eastern interior region of North America. No occurrence of any possible ancestral forebears of much of this fauna is known in the sediments immediately preceding the Tully limestone in New York, in which the Cuboides fauna is typically represented. These strange, new forms could only have originated in some more or less distant province which had been long separated from this eastern American basin, the isolation associated with different environmental surroundings being responsible for the differences in contemporaneous provincial faunas. Finally, on the culmination of slow and gradual changes in the strandlines, and perhaps in other changes, a shallow-water pathway of communication was established between the home province of the Cuboides fauna and eastern North America, and the migration was permitted which gave rise to the sudden appearance of the fauna where we now find its palentological record.

How similar is this discovery of a new province and a new outlet for the expansion of the Cuboides fauna to the discovery of the American continents by the European white races a little over four hundred years ago. Men had long sailed ships on the sea and had traveled from place to place along the Mediterranean and European shores. The first crude boats were propelled with oars; later, sailing vessels were invented and use was made of the driving force of the wind. Early sailors could not venture out of sight of land without danger of becoming lost. Then they held their courses, directed by the heavenly bodies, and finally the mag-

netic compass was discovered. This was a long, slow process, comparable to the slowly changing strandlines of the geologic past. Finally one man, more venturesome than the others, sailed away from the European shores into the unknown ocean to the west. He discovered a new continent, just as the Cuboides fauna discovered a new province in America. When once the way was pointed out, other adventurers followed, and ere long a continuous stream of white Europeans was flowing across the Atlantic.

The aboriginal peoples of our continent are comparable with the faunal predecessors in eastern North America of the Cuboides fauna. The differences between the European white races and the original Americans were as great, humanly speaking, as were the faunal differences between late Middle Devonian life and the Cuboides fauna. In each of these migrations the newcomers overran the new fields into which they entered, driving the older occupants into extinction or absorbing them into their own social organization. Geologically speaking, the change from the old order to the new, in each case, was essentially instantaneous. As soon as the pathway was established the change was complete. The few centuries which have been required to transform America from the Stone Age culture of the Indians to the age of skyscrapers, railroads, automobiles, and radio are absolutely negligible in geological history. The change has been as abrupt as the sudden change of fauna in passing from one sedimentary bed to another conformably overlying it in which the paleontological record is almost totally different.

Other analogies between human history and the paleontological record are not wanting. In late Devonian time a series of faunal migrations from the Eurasian province into North America are recognized. First came the Cuboides fauna already mentioned, which is typically represented in the Tully limestone of New York. A little later came the Intumescens fauna of the Portage beds, and this in turn was followed by the *Spirifer disjunctus* fauna of the Chemung formation. This succession of waves of migration of long extinct marine life may be compared with the successive waves of migration of the uncultured tribes of northern Europe into the confines of the Roman Empire to the south. The causes of these two series of migrations, one of the more primitive life of Devonian time, the other of human races, was essentially the same—first, the discovery in each case of the pathway along which the migration could take place, and, second, the crowding of the developing life in the original home province.

Without doubt, the most notable development in human history dur-

ing the last five hundred years has been the discovery and occupation of America by the white races of Europe. The difference in cultural development between the immigrant race and the aboriginal Americans was so great that all opposition to the newcomers was essentially negligible. The more or less crowded peoples of Europe were set free into an essentially unoccupied territory of vast extent, in which opportunity was afforded for expansional development on a far grander scale than during any similar event in all recorded human history. This opportunity for expansional social evolution is doubtless the primary cause for the rapid development in science and invention which has made the last few centuries so notable.

Similar expansional evolutions have taken place among both marine and land faunas of the past. During periods of rising sealevel relative to the land surface great areas of the lower portions of continetal surfaces have become submerged and transformed into the bottoms of more or less widely extended shallow seas. In such situations the life of the shallow seas adjacent to the expansions has been freed from its more severe struggle for existence and has been able to expand with the increasing territory suitable for its living conditions, the struggle becoming less severe between individuals and species and more a struggle between the living creatures and their environment, resembling in this respect the struggle of the early pioneers with the new American environment. A notable example of the expansional evolution of marine life under a situation such as that just mentioned is shown in the crinoidal faunas of early Mississippian age in the interior of North America. The rapid evolution of these organisms at this time led to their deployment into a greater number of genera and species than are known elsewhere in the paleontological record. From the interior province of North America as the original home of this fauna, it spread outward into distant parts of the world, the generic and specific representation becoming more and more attenuated as distances were increased.

Examples of the migratory wanderings of the now extinct faunas of the past could be multiplied almost indefinitely, but in no case is there a record of a truly worldwide, cosmospolitan fauna, either of the land or of the sea. What has hindered such a development has been the dependence of these living groups of organisms on their environmental conditions. Had a time ever existed in the past when the conditions of temperature, purity of water, salinity, and other environmental factors been uniform throughout the whole of the shallow marine waters of the earth, and at the same time had there been free means of communication be-

tween all of these shallow waters, no paleontologist can doubt that a uniform, worldwide, shallow-water marine fauna would have sprung into existence. The two factors controlling such a development are environment and the paths of communication. Perhaps a lesser degree of uniformity among the land-living creatures of the past has obtained than among those of the marine waters, for the reason that differences in environment are perhaps generally more sharply limited on land than in the shallow marine waters. The earthly habitat where the most uniform environment exists today is found in the abysmal depths of the ocean, and the life of these cold and dark abysses is essentially the same in all oceans.

In the application of these factors of environment and communication to man's distribution and social organization throughout the world, may we not look forward to results similar to those exhibited among the more lowly creatures whose recorded history carries us back for some hundreds of millions of years. In so doing the factor of environmental control may be largely or wholly disregarded, because man has been able to adapt himself to all sorts of terrestrial environment. Under these conditions the factor of communication becomes dominant.

When man was limited to his own physical efforts for means of communication from place to place, all sorts of barriers confronted him on every side. The residents of one continent were almost completely isolated from those of every other continent, and consequently their evolution progressed along wholly independent lines. Many physical features within the continents themselves were almost as insurmountable barriers as were the oceans separating the continents. Under these conditions the races and tribes of men developed extreme provincialism, just as did the faunas of the past under the conditions of isolation.

During the past few centuries conditions making for human provincialism have been disappearing with accelerating rapidity. No corner of the earth is out of touch with the rest of the world at this time. Men have visited both the north and the south poles. A trip around the world is of less moment today than a voyage across the Atlantic Ocean a few years ago. With the development of rapid transit through the agency of steamships, express trains, automobile, and airplane, man can transport himself anywhere, and with the telegraph, telephone, and radio he can communicate instantly with his fellows over vast distances. Under these conditions do not the paleontologic lessons of the past warrant our reaching the conclusion that unity and uniformity may be attained in the social and political organization of mankind in the not-distant future, judging from the time standards of the geologist?

The human race is in its infancy; it is just stepping over the threshold of its existence. The wars, the struggles, and the conflicts which engage us at this time are but the children's diseases of the race. Diseases of old age may come in the future, but these infantile ailments will doubtless be left behind. No paleontologist with his outlook on the continual forward-moving progress of living things of the past can fail to be an optimist in his outlook into the future.

While delving into the life records of the past, paleontologists have found that societies of organisms have been continually changing their characteristics; many forms and even large groups of organisms have passed into extinction; but with all of these changes there has persisted a continual forward progression. In the course of their evolution through the geologcal ages many groups of organisms have developed at some time in their history, along certain side lines of evolution, extravagant characteristics of ornamentation, apparently useless to the creatures themselves, which have culminated in the extinction of that particular phylogentic line. A notable example of this sort may be found among the Lichad group of trilobites. These creatures make their first appearance in Ordovician time. In the faunas of this period they are characterized by the presence of comparatively small tubercules and perhaps with a few short and slender spines. In the Silurian faunas they attain larger proportions and become more ornate, with numerous spines and tubercles of an extravagant sort. In our American faunas these Lichads culminate in the gigantic *Terataspis grandis* of the early Middle Devonian, a creature which attained a length of eighteen or more inches and which developed most elaborate spines, many of which bore secondary spines and tubercles. Altogether this creature must have been one of the most bizarre trilobites of all time. The Dalmanites also, another group of trilobites, originated in the Ordovician as small, unornamented individuals. In the Silurian they developed some degree of ornamentation, but in the Lower and lower Middle Devonian these ornamental characters attained the highest development and the creatures increased greatly in size. With the close of Onondagan time in America all of these gigantic and ornate trilobites became extinct, and from that time to the final disappearance of the whole class they were represented by small, unornamented forms which had persisted from early Paleozoic time without the development of such ornate features as were shown by their gigantic relatives.

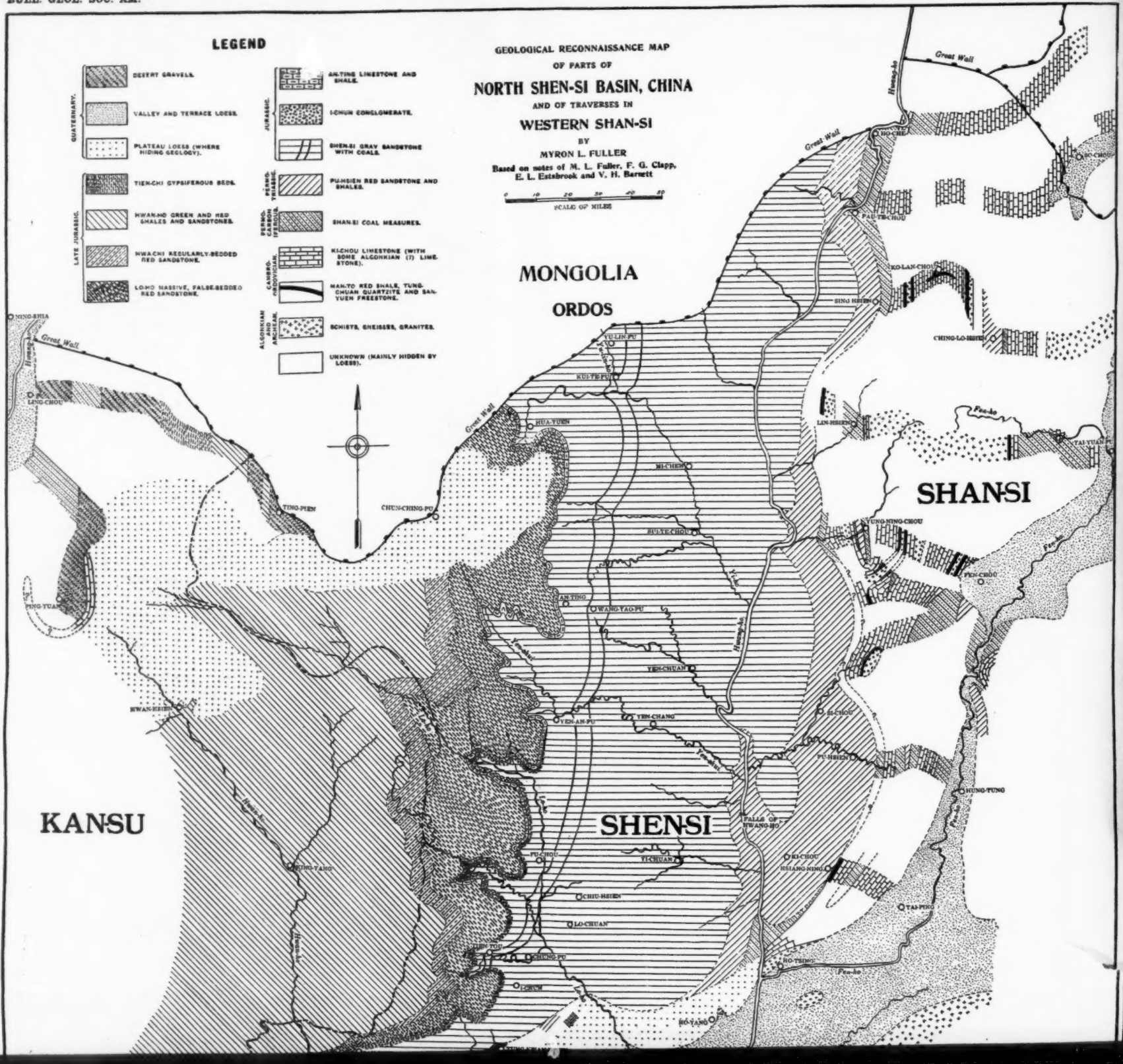
Another group of organisms with a similar history are the chambered Cephalopods. These started in early Paleozoic time with smooth shells

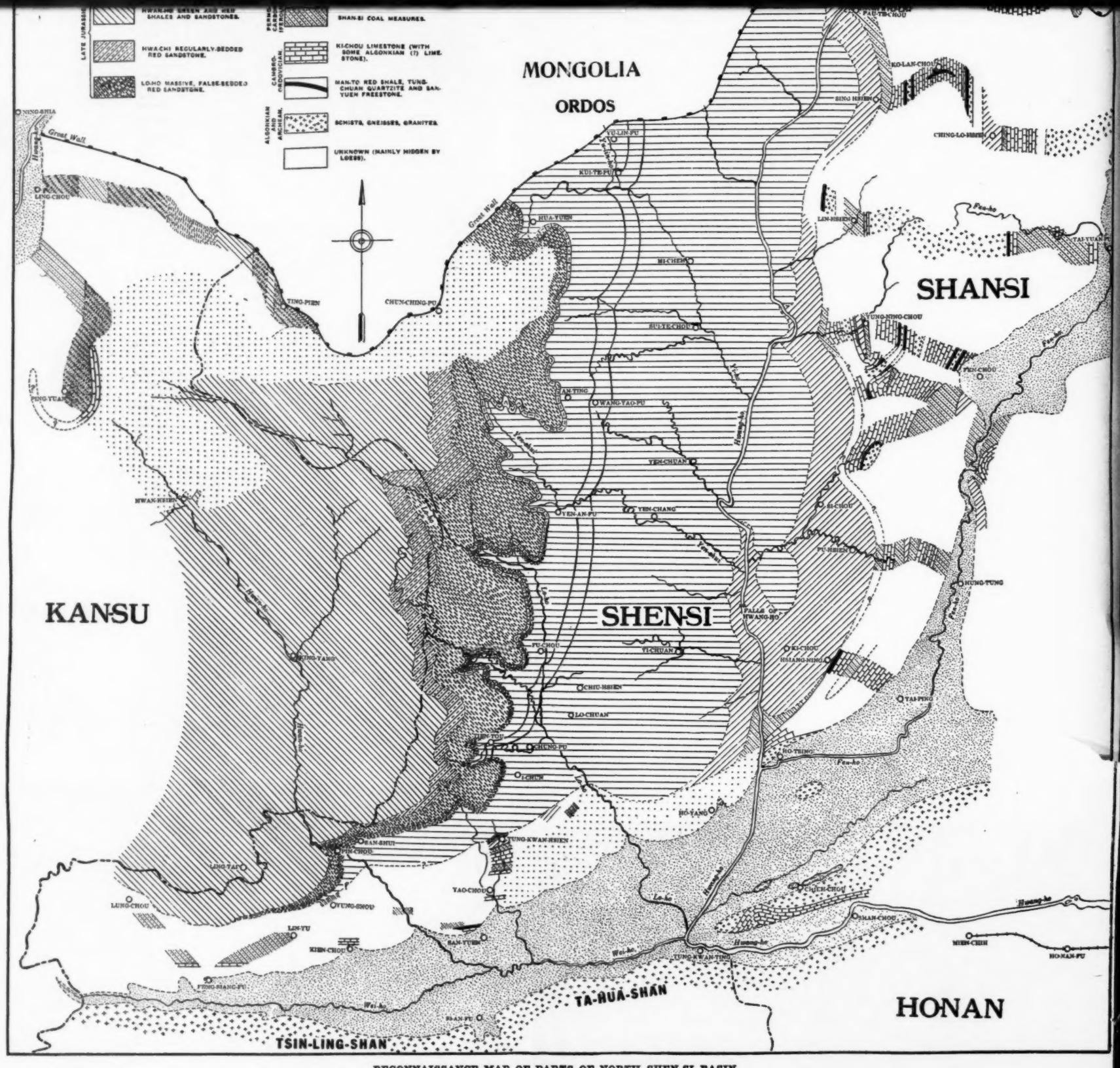
and simple sutures. By the end of Paleozoic time some of them had developed fairly complex sutures, and some shells with nodes and ribs were in evidence. Associated with these were others with sutures as simple and shells as smooth as the oldest forms. The development of increasing sutural complexity and increasing ornateness of the shells continued through Mesozoic time, when nearly the whole group became extinct. The simple sutured, smooth-shelled Nautilus alone survived, and it continues to live in the seas today as the only survivor of its race.

Additional examples, similar to those cited, could be suggested in other organic groups among both the invertebrate and vertebrate phyla of the animal kingdom. Indeed, it may be asserted with much certainty that the extravagant development of ornate characteristics is a condition preceding by no long period the extinction of the race so developing. Among living Gastropod mollusks such races as Murex and its allies, which are highly ornate with spines and processes, are doubtless rapidly approaching their time of extinction.

May not these events in the paleontologic history of creatures of the past convey a lesson to the student of human relations? Human civilizations and social organizations have arisen in the past and have dwindled and become extinct, just as have the societies of prehuman inhabitants of our earth. Their places have been taken by other social groups arising from more or less obscure sources. May not the underlying causes of the waning of both these sorts of societies be similar? Too great prosperity, perhaps, and the expenditure of vital forces in the development of ornamental characters not fundamentally of service to the race. And may not the general recognition of this lesson serve to guide, in some measure, the future destinies of humanity?

The suggestions which I have made by no means exhaust the parallelisms between the social organization of the extinct creatures of the earth and human society. Everyone who is familiar with the materials of paleontology can call to mind other comparable relations between these two social groups. I believe, however, that enough has been said to establish the fact that the dead, fossil organisms of the past can be shown to have a vital interest for students of living human society, and that these objects, long buried in the sediments of the earth's crust, can convey lessons to the present generation of men which may be of service in the guidance of our social evolution.


LEGEND
QUATERNARY.
DESERT GRAVELS.
VALLEY AND TERRACE LOESS.
PLATEAU LOESS (WHERE HIDING GEOLOGY).
LATE JURASSIC.
TIEN-CHI GYPSIFEROUS BEDS.
HWANHO GREEN AND RED SHALES AND SANDSTONES.
HWA-CHI REGULARLY-BEDDED RED SANDSTONE.
LOMO MASSIVE, FALSE-BEDDED RED SANDSTONE.
JURASSIC.
AN-TING LIMESTONE AND SHALE.
ICHUN CONGLOMERATE.
SHEN-SI GRAY SANDSTONE WITH COALS.
PERMO-TRIASSIC.
PU-MSIEN RED SANDSTONE AND SHALES.
PERMO-CARBON-IFEROUS.
SHAN-SI COAL MEASURES.
CAMBRO-ORDOVICIAN.
KI-CHOU LIMESTONE (WITH SOME ALGONKIAN (?) LIMESTONE).
MAN-TO RED SHALE, TUNG-CHUAN QUARTZITE AND SAN-YUEN FREESTONE.
ALGONKIAN AND ARCHEAN.
SCHISTS, GNEISSES, GRANITES.
UNKNOWN (MAINLY HIDDEN BY LOESS).
GEOLOGICAL RECONNAISSANCE MAP
OF PARTS OF
NORTH SHEN-SI BASIN, CHINA
AND OF TRAVERSES IN
WESTERN SHAN-SI
BY
MYRON L. FULLER
Based on notes of M. L. Fuller, F. G. Clapp, E. L. Estabrook and V. H. Barnett
0 10 20 30 40 50
SCALE OF MILES
MONGOLIA
ORDOS
SHAN-SI
SHEN-SI
KAN-SU
Great Wall
Hwang-ho
NING-SHIA
PING-LING-CHOU
TING-PIEN
CHUN-CHING-PU
HUA-YUEN
YU-LIN-PU
KUI-TE-FU
MI-CHEN
KU-TE-CHOU
AN-TING
WANG-YAO-PU
YEN-CHUAN
YEN-AN-FU
YEN-CHANG
KWAN-HSIEN
PU-CHOU
YI-CHUAN
CHIU-HSIEN
LO-CHUAN
TIEN-YOU
CHUNG-PU
HO-TANG
PAO-TE-CHOU
KO-LAN-CHOU
SING HSIEN
CHING-LO-HSIEN
LIN-HSIEN
TAI-YUAN-FU
TUNG-NING-CHOU
PEN-CHOU
FU-CHOU
FU-HSIEN
HUNG-TUNG
FALLS OF HWANG-HO
KI-CHOU
HSIANG-NING
TAI-PING
HO-TSING
Fen-ho
Yenshui
Kuan-ho
Lo-ho



RECONNAISSANCE MAP OF PARTS OF NORTH SHEN-SI BASIN

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 38, PP. 287-378, PL. 8 JUNE 30, 1927

GEOLOGY OF THE NORTH SHEN-SI BASIN, CHINA[1]

BY MYRON L. FULLER[2] AND FREDERICK G. CLAPP[3]

(Presented by title before the Society December 29, 1926)

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[1] Manuscript received by the Secretary of the Society February 1, 1927.
[2] 60 Main Street, Brockton, Massachusetts.
[3] 50 Church Street, New York City.

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Introduction

Location of area

The North Shen-si Basin is a great oval sedimentary trough (figure 1) measuring about 450 miles from north to south and 250 miles from east to west, lying chiefly in northern Shen-si, but extending into Mongolia, Shan-si, and Kan-su. Its area is approximately 100,000 square miles.

The great northern loop of the Hwang-ho roughly marks the northern limits of the basin; the high mountains of western Shan-si bound it on the east; the southern rim is not far north of the fault-front of the Ta-hua and Tsin-ling mountain ranges, extending westward across Shen-si from the acute bend of the Hwang-ho at the southwest corner of Shan-si, while the broken north-south mountains of east-central Kan-su border it on the west.

The northern third of the basin lies within the sandy or gravelly deserts of the Ordos, while the southern two-thirds, separated from the northern

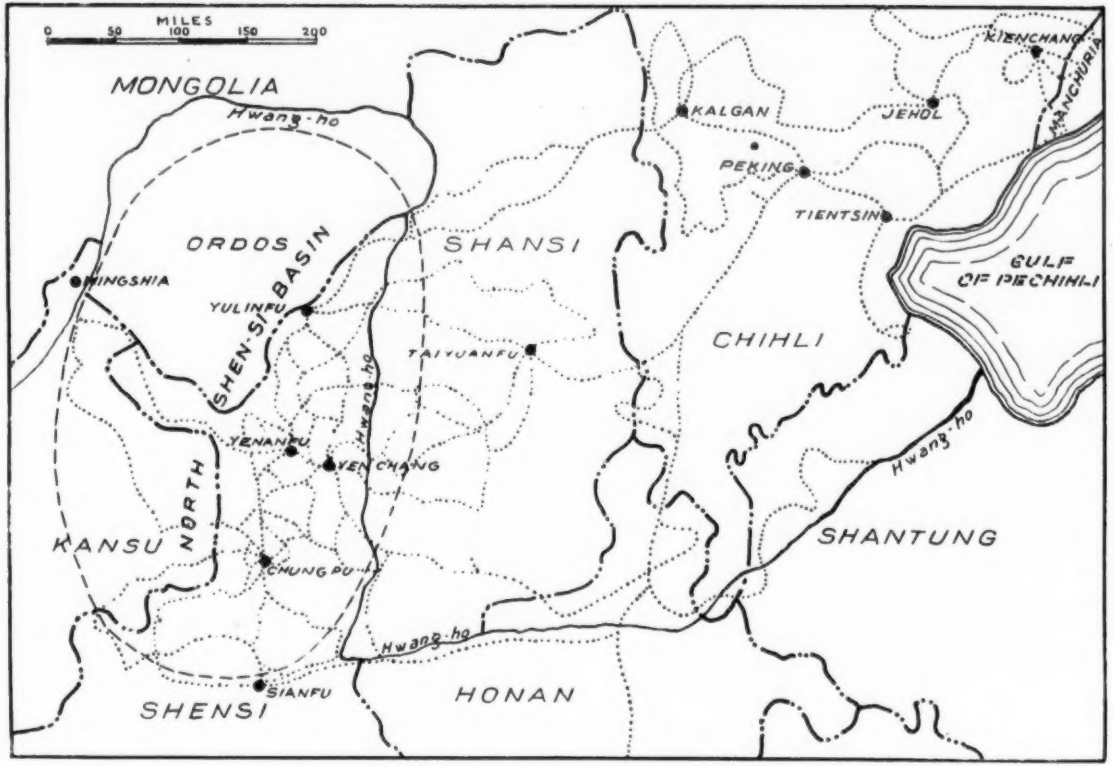

FIGURE 1.—*Index Map showing Location of the North Shen-si Basin*
Principal traverses indicated by fine dotted lines.

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section by a line approximately coinciding with the Great Wall, here forming the Mongolia-Shen-si boundary, lies in the great loess region of China.

The description of the hitherto undifferentiated sediments and of the structure of this basin, named by the writers from the section of the province in which a large part of its deposits are found, is the object of this paper.

OUTLINE OF EXPLORATIONS

In connection with economic explorations for American clients cooperating with the Chinese Government, the writers and their associates ran, in 1914 and 1915, nearly 20,000 miles of geological traverses in the provinces of Chih-li, Shan-tung, Ho-nan, Shan-si, Shen-si, and Kan-su and along the borders of Manchuria and Mongolia (figure 1). Of the routes traveled, nearly half were in the North Shen-si Basin or the vicinity of its rim. An area of more than 50,000 square miles was covered by reconnaissance, 400 miles of stadia-levels run, and several hundreds of square miles surveyed in detail by plane-table within a period of nine months, the available limit of the concession under which the work was executed.

FIELD METHODS

In general each geological party traveled on horseback, but camels and river junks were occasionally utilized. Supplies were ordinarily transported by mules. Mule-trails were followed almost exclusively, since, except for a few "feeders" and the single cart-road from the railroad in Ho-nan to Si-an-fu, Shen-si, thence north to Yen-an-fu and east to Yen-chang, the province of Shen-si is without roads. Soldiers and guides accompanied each geologist.

Since villages were seldom more than a few miles apart, camping was rarely necessary. Quarters were exceedingly varied and included loess caves, mud huts, native inns, temples, magistrates' yamens, rest houses, warehouses, native shops, commercial bureaus, police stations, schoolhouses, rooms of anti-opium and anti-footbinding societies, and missionary buildings.[4]

An unusually rapid method of reconnaissance mapping was developed to meet the demands imposed by the limited time available for the work.

[4] Myron L. Fuller: Explorations in China. Bull. Am. Assoc. Petrol. Geols., vol. 3, 1919, pp. 99-116.

As elsewhere described in detail,[5] the system involved the running of compass lines and the mapping of the geology *from horseback while in motion,* and in spite of its rapidity proved substantially accurate, the errors being inappreciable on maps of reconnaissance scale.

Although not affecting the economic results of the explorations, it is greatly to be regretted that no paleontologist was attached to any of the parties and only approximate age determinations could be made.

AVAILABLE DATA

Field-work was continued by the writers almost to the moment of their return to the United States, when all notebooks pertaining to Shen-si and Kan-su were turned over to their clients. These, with the notes of their associates, were subsequently lost in the confusion following the death of three successive officials in charge of the China work. The writers have, therefore, necessarily been compelled to rely largely on tracings compiled by draftsmen from the field-notes after their departure from China, and hence without checking or revision. The subdivisions and characteristics of the principal deposits of the North Shen-si Basin are, however, definitely known, and only in minor details is there, in general, a material deficiency of data.

CHINESE NAMES

There is no established system for the spelling of Chinese names in English. The spellings adopted by the China Inland Mission and the British-managed post-office department are most commonly followed, but these are not always in accord with one another. In the present paper the attempt has been made to follow the spellings in most common English use, and which are most likely to be found on existing maps, rather than the equally variable European forms, which involve apostrophes and various accents, which are meaningless to English readers and hinder rather than aid identification and pronunciation of the words. Although it is common for English and other writers to unite the parts of place names into continuous words, the writers have adopted the alternative practice of separating them by hyphens. This shows the correct subdivision and aids pronunciation of the component syllables, each of which is really a separate Chinese word, with its distinctive written and printed characters. Certain non-Chinese words, such as Mongolia, Manchuria, and Ordos, are exceptions.

[5] Myron L. Fuller: Quick method of reconnaissance mapping. Econ. Geol., vol. 14, 1919, pp. 411-423.

The terminations hsien, pu, fu, chou, or chow indicate cities of varying political rank, and their use or omission does not, as a rule, affect the significance or identification of a name. Hsien is the common designation of a subdivision similar to our county. Shan is the word for hill or mountain, while ho and shui are designations for rivers or streams.

The names of Chinese towns and smaller cities are constantly changing, and some have two or more names in common use. The attempt is here made to use the form in most general use.

ACKNOWLEDGMENTS

Most cordial recognition is given to the writers' geological associates (including Frank A. Herald, who succeeded them on their return to America; Victor H. Barnett, Edward L. Estabrook, Ernest Marquardt, and John M. Lovejoy) for data from the maps of their traverses, which constitute nearly half of those made within the province of Shen-si. Credit is likewise due to L. E. Gale and A. D. Hill for elevations determined by stadia-levels and for topographic plane-table surveys of special areas, and to T. P. Killian for the drafting of maps.

Special acknowledgment is due to the Chinese Government, which shared the cost of the explorations, and to Hsiung Hsi-ling, Director of the National Oil Administration, who made many inquiries by letters and telegrams and who provided the different parties with special passports, arms permits, guards, and deputies serving as interpreters and paymasters. To these deputies, often highly educated and splendid men personally, who were the geologists' only English-speaking companions for long periods, sincere thanks are due. To C. Y. Chiu, Ho Yen Sun, Wu Kuei Ling, Munsey Lew, and others special acknowledgment is made for loyal and efficient services. Mr. K. T. McCoy rendered invaluable assistance in the preliminary preparations, party management, and supervision of transportation.

President Yuan Shi Kai and the governors of Shen-si and adjoining provinces aided the explorations, and many local officials furnished guides and information and often hospitably entertained the geologists in the field. Appreciation is also due to the common people for help extended. Only in rare instances was there the slightest indication of unfriendliness or of overcharge, extortion, or opposition.

Credit for age determinations, as specifically acknowledged elsewhere in the text of the paper, is due to the publications of the members of the Geological Survey of China, which, following its organization, some five years after the completion of the writers' investigations, collected and identified fossils at a number of points.

Finally, special thanks are due to the writers' clients, who, after the necessity ceased for holding the data as confidential, generously granted permission for the publication of results without restriction other than that their names should not be used.

RESULTS OF INVESTIGATIONS

It was the good fortune of the writers to be the first geologists, so far as known, to visit and explore the great but almost unknown North Shen-si Basin. Although Richthofen's maps[6] show the supposed formations as far west as the Hwang-ho in Shan-si and along the southern rim of the North Shen-si Basin in Shen-si, the mapping was based on deduction only, as he did not personally penetrate west of the Fen-ho, 50 to 75 miles east of the Hwang-ho in central Shan-si, nor much north of Si-an-fu in Shen-si. A natural inference from his mapping, which has proved inaccurate in the area mentioned, was that the greater part of northern Shen-si would be found to be underlain by flat-lying Carboniferous rocks; but Willis and Blackwelder,[7] after their careful studies of the continental structure of Asia, made no attempt to predict the nature or age of the formations beneath the 500- to 2,000-foot mantle of silt which covers the area, but mapped northern Shen-si simply as loess.

The writers' investigations proved that, in spite of its great thickness, the loess is not the all-obscuring mantle often assumed, and that the geology could be worked out in considerable detail from exposures in the bottoms of the trenches cut by the larger streams through it into the rock beneath. The north Shen-si region was found to be a great basin occupied by upward of 20,000 feet of consolidated sediments from Cambro-Ordovician to Jurassic in age, with many hundred feet of Cretaceous and Tertiary gravels in places, in addition to the loess and the more recent deposits. About twenty formations or phases were differentiated, including three of Cambro-Ordovician, one Permo-Carboniferous, one Permo-Triassic, ten Jurassic, one Cretaceous, one Tertiary, the Tertiary-Pleistocene loess, and various Recent deposits.[8] The beds of the great trough, which the writers have called the North Shen-si Basin, have a general dip toward the center on the east and south, but on the west they probably abut against great faults. The north rim was unvisited. A belt of strongly folded Cambro-Silurian to early Mesozoic rocks, often

[6] Ferdinand von Richthofen: Geologic atlas of parts of China.

[7] Bailey Willis and Eliot Blackwelder: Research in China. Carnegie Inst. of Wash., vol. 2, 1907, plates 4, 5, and 6.

[8] Age assignments are in accordance with fossiliferous determinations made subsequently by the China Geological Survey or its members.

with Archean or Algonkian cores, the whole faulted into a series of horsts and grabens, surrounds the basin on all sides.

Brief outlines of the geology and some of the economic resources of the region have been given in earlier publications,[9] but the present paper is the first detailed presentation of the results of the explorations in the North Shen-si Basin.

GEOGRAPHY

GENERAL FEATURES

The relations of the north Shen-si area to other parts of northeastern China are similar to those of the northeastern Ohio region of the United States. Immediately east lies the folded and faulted mountainous region of western Shan-si, corresponding to the Alleghany ridges of western Pennsylvania, while beyond, in the same direction, is the central Shan-si coal basin, comparable, in a way, with the Pennsylvania anthracite field, the eastern Shan-si Mountains with granitic cores analogous to the Blue Ridge, and the coastal plain overlying a surface of crystalline or metamorphic rocks, peaks of which rise as monadnocks above its surface. In the extreme northeast, in a position similar to that of New England, and like it underlaid by sharply folded Mesozoic and older sediments and intrusives, is the mountainous region of northern Chihli and Manchuria. On the west the region is bounded by discontinuous mountain ranges not unlike the broken southern portions of the American Rockies in New Mexico and western Texas.

[9] Myron L. Fuller: Explorations in China. Bull. Am. Assoc. Petrol. Geols., vol. 3, 1919, pp. 99-116.

Frederick G. Clapp: Discussion of "Petroleum resources of China and Siberia," by Eliot Blackwelder. Trans. Am. Inst. Min. and Metal. Engrs., vol. 68, 1923, pp. 1109-1111.

Myron L. Fuller and Frederick G. Clapp: Formations of the North Shensi Basin, China. Jour. of Geol., vol. 34, 1926, pp. 434-440.

Myron L. Fuller and Frederick G. Clapp: Revision of coal estimates for West Shansi, China. Econ. Geol., vol. 21, 1926, pp. 743-756.

Myron L. Fuller and Frederick G. Clapp: Notes on coals of Shensi and East Kansu, China. Econ. Geol., vol. 22, 1927, pp. 62-79.

Myron L. Fuller and Frederick G. Clapp: Oil prospects in northeastern China. Bull. Am. Assoc. Petrol. Geols., vol. 10, 1926, pp. 1073-1117.

The following geographic papers have also appeared:

Frederick G. Clapp: Along and across the Great Wall of China. Geog. Review, vol. 9, 1920, pp. 221-249 and map.

Frederick G. Clapp: The Hwang Ho, Yellow River. Geog. Review, vol. 12, 1922, pp. 1-18.

Myron L. Fuller: Some unusual erosion features in the loess of China. Geog. Review, vol. 12, 1922. pp. 570-584.

Myron L. Fuller and Frederick G. Clapp: Loess and rock dwellings of Shensi, China. Geog. Review, vol. 14, 1924, pp. 215-226.

DRAINAGE

The entire North Shen-si Basin is drained by the Hwang-ho, or Yellow River. This great stream rises in the Ko-ko-nor region of northeastern Tibet and flows in great zigzags in deep valleys, probably structural, between high mountains, northeastward into Kan-su; thence, in the same general direction, across the decreasingly mountainous country at the east end of the Nan-shan ranges, into the loess and desert regions of the northeastern portion of the province.

Entering the reduced northwest rim of the North Shen-si Basin near the northeast "panhandle" of Kan-su, it flows in broad swings, with occasional abandoned channels lying many miles north of its present course, in a shallow and often poorly defined valley extending in a great loop around the north end of the sandy Ordos. Then, at a point a few miles west of the mountains which mark the east rim of the basin in western Shan-si, it turns abruptly south into a deep gorge which forms the boundary between Shan-si and Shen-si for 500 miles. This portion of its course coincides with a broader and shallower pre-loess valley, but the canyon is of a date subsequent to the loess accumulation.

At the southwest corner of Shan-si the Hwang-ho makes an acute bend to the east and follows a fault valley between Shan-si and Ho-nan to the coastal plain, over which it meanders in ever-shifting channels to the sea.

In the western and northern portions of the Ordos, the sandy southern division of the Mongolian desert, the minor drainage is by short, intermittent streams into the Hwang-ho. In the central region the drainage is indefinite, many of the streams drying up or leading to salt or brackish lakes. On the east a fairly well developed drainage leads to the now deeply intrenched Hwang-ho, while the southern Ordos is beginning to be tapped by the drainage of north Shen-si.

Although some of the Shen-si tributaries of the Hwang-ho head within comparatively short distances of higher portions of the same stream in northern and central Kan-su, they are separated from it by the more or less elevated rim of the North Shen-si Basin, the entire drainage of eastern Kan-su and northern Shen-si being carried southeastward into the north-south reach of the Hwang-ho or its westerly tributary, the Wei-ho, which lies north of the fault-front of the Tsin-ling-Ta-hua mountain ranges to the Hwang-ho at its eastward bend.

The courses of most of the tributaries correspond with the slope of the surface of the loess mantle. When cutting through the latter into the underlying formations the streams continue in the same general direction, with little reference to the hardness or structure of the rocks.

With the exception of the Fen-ho, which issues from a structural trough outside the limits of the North Shen-si Basin, the Shan-si tributaries of the Hwang-ho are only a few miles in length.

Although the larger streams are rather widely spaced, their minor tributaries ramify in every direction and cover most of the intervening territory. Unreduced remnants of the loess plateau, however, frequently separate the headwaters of the different stream systems, while narrower, flat-topped ridges occur between many of the parallel or converging streams.

The Yi-ho and Yen-shui flow on loess in their upper reaches, but cut into the rock in their lower sections. The Lo-ho and Hwan-ho likewise flow in loess near their heads, then in rock in their central portions, finally running over fillings of reworked, water-deposited loess in the downfaulted region of their lower courses. The Wei-ho flows on material of the latter character throughout much of its course.

Topography

General features

The north Shen-si region is a topographic as well as a geologic basin, consisting of a trenched central plain of loess rimmed by mountains on the east, south, and west. On the north the loess surface merges into the sandy wastes of the Ordos or locally rises above them. Above the general level of the basin represented by the flat loess-plateau remnants, rock monadnocks rise from place to place, while below it are the valleys, gorges, and ravines cut by late Quaternary drainage into the loess or the underlying rocks.

Loess surface

The loess of northern Shen-si and adjoining regions is essentially a basin filling, with flat center and slopes rising gently to the mountainous rims of the basin on the east and west, the higher portions of which are either destitute of loess or covered only in spots. In the northeast, near the Great Wall, the loess disappears under the later sands of the southern Ordos, but in the northwestern arm of Shen-si it terminates in a thousand-foot loess scarp facing the desert. On the south the loess breaks away in a series of steps or terraces facing the Wei-ho, which has removed most of the material which originally rested against the Tsin-ling-Ta-hua Mountains on the south side of the valley, although leaving pronounced loess terraces in places.

The inclination of the loess surface corresponds in its general direction to that of the rock beneath (figure 20), but is steeper and somewhat more

uniform. The altitude of its unreduced portions is about 500 feet higher than that of the rock at the Hwang-ho along the Shan-si-Shen-si line, and from 1,000 to 1,500, or possibly 2,000 feet, higher at points near the basin rim in northwestern Shen-si and eastern Kan-su.

The loess plateau is everywhere dissected by streams, which often cut deeply into the underlying rock. The major streams, including the Hwang-ho and its principal tributaries, appear to have remained substantially in their pre-loess valleys and are now trenched in their bottoms. The Wei-ho is the only important exception, flowing on a filling of unknown depth in the trough resulting from faulting along the north face of the Tsin-ling-Ta-hua ranges. The headwaters of all streams ramify in loess channels unrelated to the buried rock topography.

Between the valleys and ravines of the existing drainage system are numberless flat-topped remnants of the loess plateau. Many of them, especially those between nearly parallel streams, are some miles in length, but few are of any great breadth or area. Erosion is everywhere active at the present time, and vertical-walled canyons and ravines, pinnacles, sinks, natural wells, bridges, caves, tunnels, and other striking loess forms are common.[10]

SUBLOESS ROCK SURFACE

Below the surface of the loess plain or plateau at depths ranging from 500 to nearly 2,000 feet, is the buried beveled surface of the tilted sedimentary rocks of the basin (figure 18). On the east this old rock surface slopes toward the Hwang-ho from altitudes of 8,000 feet or more in the northern and 4,000 to 5,000 feet in the southern sections of the West Shan-si Mountains to elevations of 3,000 and 2,500 feet at corresponding portions of the river. On the west the slope is southeasterly toward the Hwang-ho and Wei-ho from 4,700 feet in northwest Shen-si and 9,000 feet in central Kan-su to 2,500 feet along the former and to an unknown depth below the silts in the fault-trough below the latter.

The surface on which the loess was deposited was not a peneplane, but seems to have been broken by stream valleys of some width and depth and by monadnocks of considerable size. The immediate valley of the Hwang-ho along the Shan-si-Shen-si line was apparently at least 500 feet in depth and had a width of several miles. While it is difficult to determine the extent and depth of the pre-loess valleys of the tributary streams, it is probable that those of the Li-ho, Yen-shui, Lo-ho, and

[10] Myron L. Fuller: Some unusual erosion features of the loess of China. Geog. Review, vol. 12, 1922, pp. 570-584.

Hwan-ho were approximately as deep as that of the Hwang-ho in their lower courses, although the valleys did not apparently exceed 100 feet in their upper sections.

POST-LOESS ELEVATIONS

During and subsequent to the deposition of the principal loess mass western Shan-si underwent an uplift accompanied by step faulting, as a result of which, since later erosion has been limited chiefly to the removal of loess from the higher elevations and the cutting of gorges, the present elevations of 6,000 to 10,000 were attained. In general the topographic axes coincide with heavy masses of the resistant Ki-chou limestone, but occasionally with Archean or Algonkian areas. Faulting has had much to do with the major topographic features, as in the 'O-shan horst and Ping-yang graben. Minor and more recent features are chiefly governed by the hardness of the rocks.

In Shen-si the uplift of the Tsin-ling and Ta-hua Mountains to their present altitudes of 6,000 to 7,000 feet above the plains in front of the fault-scarp constituting their northern face, was completed (figure 5). North of the Wei-ho, although all beds are folded and faulted, the disturbance occurred mainly in the Jurassic, and the elevations were greatly reduced in the Cretaceous and Tertiary before being covered by loess. Nothing like the mountainous areas of west Shan-si is found, even the Ki-chou being marked only by relatively low elevations.

Mountains occur on the west and north rims of the North Shen-si Basin, but to what extent their present relief is due to Quaternary elevation is not known.

Stratigraphic Succession

INTRODUCTION

With few exceptions, the rocks of the North Shen-si Basin, aside from the great Cambro-Ordovician limestone, consist of beds showing great variability both vertically and horizontally. While certain of the component strata are sometimes sharply defined locally, the individual beds can seldom be traced laterally for more than a mile or two. Nevertheless, they may be grouped into aggregations of fairly definite and persistent lithologic characteristics, which may be recognized and mapped over broad areas. These constitute the units of the present paper. They are really series, but because of the specific rather than general application of the term by many, they are here designated as formations. Where the characteristics of a group or formation vary considerably in its different

GEOLOGICAL COLUMN

			Common thickness (feet)
Recent	Recent loess, stream alluvium, dunes, and gravels on old loess, etc		Several hundred
	Disconformity.		
Pleistocene	Main loess body (Huang-tu formation) with internal unconformities		1,500
Tertiary	Basal sandy loess, etc. (Huang-tu formation)		500
	Local subloess gravels, etc		1,000
	Disconformity		
Cretaceous (Late)	Lung-chow formation. Subloess gravels, sands, and clays		1,000+
	Unconformity (peneplanation).		
Jurassic	Tien-chi formation (gypsiferous beds)		(?)
	Hwan-ho formation (3,000±feet)	Hwan-hsien phase: Bright greenish shales and sandstones (little red)	600
		King-yang phase: Alternating green and red sandstones and shales	1,800–2,500
		Tan-pa-li phase: Red sandstone and shale (little green)	0–600
	Hwa-chi sandstone	Regularly bedded red sandstone with little shale	1,000
	Lo-ho sandstone	Massive cross-bedded red sandstone	2,000
	An-ting limestone	Limestone and red shale (northern equivalent of I-chun) (200 feet)	200–500
	I-chun conglomerate	Conglomerate, etc. (southern equivalent of An-ting) (500 feet)	
	Unconformity		
	Shen-si formation (6,000–7,000 feet)	Tien-tou phase: Massive gray to pink sandstones with some shale	800–1,500
		Yen-an-fu phase: Coal Measures with massive sandstone at top and bottom	1,000
		Yen-chang phase: Dense, hard, thin-bedded gray sandstones	4,000
Permo-Triassic (?)	Pu-hsien formation	Sandstone and red shale	2,000
Permo-Carboniferous	Shan-si formation	Upper Coal Measures (Permian)	600
		Disconformity.	
		Lower Coal Measures (Lower and Middle Carboniferous)	400
	Disconformity.		
Cambro-Ordovician	Ki-chou limestone	Massive gray limestone.	5,000
	Man-to shale	Red shale with some quartzite	200–350
	Tung-chuan quartzite and San-Yuen freestone	Both quartzites include a little red shale and represent respectively eastern and western phases	500
	Disconformity.		
Algonkian	Schists, etc., with internal unconformities.		
	Unconformity.		
Archean	Gneisses, schists, intrusive granites, etc.		

parts but do not appear to be sufficiently definite to warrant separate recognition, the term "phase" is applied. In some cases, especially in the coal-bearing formations, certain of the beds may be differentiated as members or lenses, but they are of local interest and significance only.

The succession as worked out by the writers on the ground is presented in the geological column given on the preceding page. Lithologic designations were chiefly used in the field, except for the Shan-si and Shen-si formations. Other formation names were first applied in a preliminary paper, "Formations of the North Shensi Basin."[11]

Archean: Tai-shan Complex

Introduction

The story of the Archean, as usual, is lost in the indecipherable aggregations of gneisses and schists of indeterminate origin, of sheared and plicated masses of ancient igneous or highly metamorphosed rocks which, although sedimentary, are hopelessly involved in their relations to others, and of great bodies of granites intruded in the latter part of the period, but before the long interval of erosion marking the unconformity preceding the Algonkian. To this old rock complex the name Tai-shan was applied by Willis and Blackwelder. In character and structure it is similar to the Archean of the Lake Superior region of America.

West Shan-si Exposures

Outside of the eastern rim of the North Shen-si Basin in western Shan-si ancient crystalline and metamorphic rocks are exposed at many points beneath the Cambro-Ordovician quartzite or limestone along a number of long north-south uplifts. The component beds are exceedingly variable in character and include gneisses, schists, and intrusions of acid granite as well as of more basic igneous rocks. Most of the beds, except the granites, are strongly metamorphosed and characterized by shearing, contortions, flow structures, or stretching. The granites, which are often banded, commonly occur in the central portions or cores of the uplifts, with schist on the sides.

The rocks are of Archean aspect and are tentatively assigned to that age, although the unreliability of appearance as an indication of age is fully realized. The work of Willis and Blackwelder has shown that both the Archean and Algonkian are represented on the eastern border of the most easterly of the ancient rock-masses of western Shan-si, and it is probable that the same is true of the westerly uplifts.

[11] Jour. of Geol., vol. 34, 1926, pp. 434-400.

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[11] Jour. of Geol., vol. 34, 1926, pp. 434-400.

Although outside the limits of the area assigned to the writers for investigation, the west Shan-si region was crossed at ten points by parties on their way to or from the North Shen-si Basin (figure 2). The areas of probable or possible Archean encountered on these routes are indicated below.

On Route 1 an area of gneisses and metamorphic rocks 5 miles in width was crossed by Estabrook 25 miles west of Tso-yuen-hsien and about 50 miles east of the Hwang-ho (figure 19). The rocks were regarded as probably Algonkian (Wu-tai), but may include some Archean. They are cut by basic intrusions, probably of Mesozoic age. On Route 2 Clapp found no indication of Archean (figure 20).

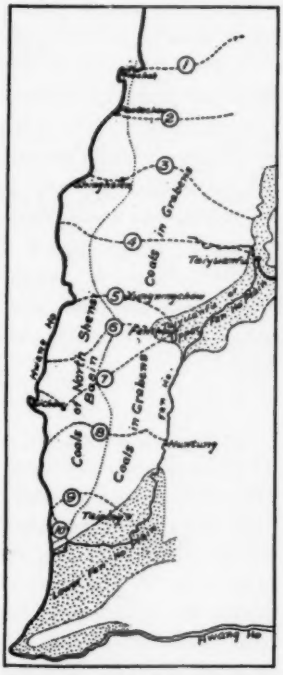

FIGURE 2.—*Sketch showing Locations of geological Traverses in western Shan-si*

On Route 3 granites, gneisses, and schists, with pegmatitic and basaltic intrusions, occur in a belt 25 miles wide immediately west of Sin-chou, in the valley north of Tai-yuan-fu (figure 21). The schists and some of the gneisses show alterations of dark hornblendic with lighter acid layers. Much of the granite is light pink in color. A few small lenses of basic intrusions occur throughout the belt, but the chief development of basic rock is near the contact with the overlying Ki-chou limestone on the west, presumably along fault-lines. Estabrook assigned the older rocks to the Tai-shan complex. The basic intrusives were not noted in the limestone, which is suggestive of a pre-Cambrian age, but they may be as late as Mesozoic. The core of a 7,000-foot range of mountains crossed between Ko-lan-chou and Sing-hsien on the same route consists of diorite gneiss.

Beginning about 30 miles west of Tai-yuan-fu, on Route 4, and continuing westward for nearly 50 miles, Barnett reported gneisses and schists with local marbles, assigning them to the Tai-shan complex (figure 22). A belt of similar rocks, 1½ miles wide, occurs 15 miles

west of the preceding, beyond an intervening sedimentary basin. The same geologist reported granites and schists in a belt about 3 miles wide at a point 5 miles southwest of Yung-ning-chou (Shih-hsien), on Route 5 (figure 23), while Fuller noted two areas of granite, one-half and 3½ miles wide, underlying Tung-chuan quartzite 15 miles east of the same city. Granite is also probably present beneath the loess between quartzite exposures 7 miles northwest of Fen-chou.

On or near Route 6, Clapp, Fuller, and Barnett found granites and schists beneath the Tung-chuan quartzite at four or more localities from 15 to 20 miles south of Yung-ning-chou (figure 24). The granites, at least, are probably Archean. Granite was found by Clapp below the Ki-chou limestone and Tung-chuan quarzite (?), about midway between the Hwang-ho and Fen-ho, on Route 7 (figure 25).

No Archean rocks were noted on Routes 8 or 9. On Route 10 coarse red granite was seen by Fuller below cherty limestone, possibly Algonkian in age, just north of the Fen-ho plains (figure 28). The top of the granite here and in certain other localities is marked by a peculiar deep reddish zone of some thickness, suggesting pre-Algonkian weathering and disintegration, with possibly some arkose. The mass is cut by quartz veins.

CENTRAL SHEN-SI EXPOSURES

Large areas of granite occur in the Ta-hua, the mountainous range bounding the south rim of the North Shen-si Basin east of Si-an-fu, while other areas are found in the Tsin-ling range west of the city named. These have sometimes been regarded as Archean, but Willis and Blackwelder, who crossed the latter range just west of Si-an-fu, regarded the granites as Mesozoic intrusives, while the oldest schists were Proterozoic (figure 5).[12] Elsewhere[13] they state that "the Tai-shan (Archean) complex is not represented," the rocks in the vicinity of the basin rim, apart from the granitic and other intrusives, being much metamorphosed sediments of Algonkian, Paleozoic, and later age. The absence of the Archean where actual examinations have been made casts doubts on the general presence of rocks of this age along the southern rim of the North Shen-si Basin, as shown on the maps of Richthofen's atlas.

The presence of Archean rocks on the north and west sides of the basin is likewise unestablished.

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[12] Research in China. Carnegie Inst. of Wash., Atlas, Map A 2, etc., 1907.
[13] Ibid., vol. 1, pt. 1, p. 299.

PROTEROZOIC: ALGONKIAN

INTRODUCTION

The period of profound folding and metamorphism of the Archean was followed by one of powerful erosion, but beyond the fact that it was of a pronounced character little is known of the resulting unconformity.

The Algonkian in the type region of eastern Shen-si was divided by Willis and Blackwelder as follows:[14]

Subdivisions of the Algonkian

Hu-to system (Neo-Proterozoic)	Tung-yu limestone Tou-tsun slates	Slates, limestone, and quartzite.
	Unconformity.	
Wu-tai system (Eo-Proterozoic)	Si-tai series	Chiefly chlorite schist; quartzite conglomerate at base.
	Unconformity.	
	Nan-tai series	Siliceous marble, jasper, quartzite, and schist.
	Unconformity.	
	Shi-tsui series	Mica schists, gneiss, magnetite quartzite, and basal feldspathic quartzite.
	Unconformity.	

The foregoing outline shows an early deposition of predominantly quartzitic sediments, followed by more calcareous and later by argillaceous beds, still, however, with considerable amounts of quartzose material. The first three series, with two separating unconformities, were folded into isoclines, intruded by igneous rocks, metamorphosed into gneisses, schists, and marbles, and finally severely eroded before the inauguration of the latest depositional stage, represented mainly by a considerable thickness of slates with some limestone and quartzite.

WEST SHAN-SI EXPOSURES

On the ten traverses across western Shan-si (figure 2) schists and cherty limestones, presumably belonging in part at least to the Wu-tai and Hu-to systems, were recognized at several points, but the detailed studies necessary to differentiate them from the Archean schists on the one hand and the Ki-chou limestone on the other were not permitted by the nature of the writers' instructions and work.

As mentioned in the discussion of the Archean, a 5-mile-wide belt of metamorphic rocks on Route 1 (figure 19) was originally correlated with the Wu-tai by Estabrook, but is believed to be in part Archean.

[14] Op. cit., vol. 2, p. 4.

On Route 2 (figures 4 and 20) certain metamorphic limestones and limestone conglomerates, further described under Ki-chou limestone, named.

were noted by Clapp. While of distinctly Algonkian aspect, their associations and structural relations favor their assignment to the limestone

The schists west of Sin-chou on Route 3, as has been stated, are regarded as chiefly Archean, although possibly including some Algonkian (figure 21). The 6,600-foot mountain 10 miles northwest of Ching-lo-hsien consists of a metamorphic series starting with a pink quartzite, darker and denser than the Tung-kwan, passing downward into basic schistose or gneissoid beds to a massive limestone (Algonkian ?), much darker and more greenish than the Ki-chou, which is the most prominent member of the series and forms the summit of the range (Estabrook).

The schists of Route 4 are regarded as probably chiefly Archean, but the marbles and possibly some of the schists may be of Algonkian age (figure 22). The position of the schists between the Archean granite and the Tung-chuan quartzite or Ki-chou limestone on Routes 5 and 6 (figures 23 and 24) suggests an Algonkian age, but their characteristics are more nearly those of the Tai-shan complex. Along or near Route 9, in the region known as the 'O-shan or Ngo-shan, Clapp noted brecciated and conglomeratic limestones of Algonkian aspect, but they appear to lie above a conspicuous quartzite, presumably the Tung-chuan; hence are probably to be referred to the Cambro-Ordovician (figure 27).

On Route 10 a massive limestone was noted by Fuller above a red banded Archean granite and below the Shan-si coal measures (figure 28). The basal portion, at least, carried much chert and corresponds in its physical characteristics with the Hu-to (Algonkian) rather than with Ki-chou limestone (Cambro-Ordovician), which, "in strong contrast to the Algonkian limestones," according to Blackwelder,[15] is never flinty.

CENTRAL SHEN-SI EXPOSURES

Where the Tsin-ling and Ta-hua mountain mass constituting the south rim of the North Shen-si Basin was crossed by Willis and Blackwelder, the north, or frontal, portion, 5 to 10 miles in width, was found to consist of Kan-yu-wan schist of Algonkian age (figure 5), described in their atlas as a "chloric schist with beds of dense siliceous limestone and quartzite." Back of this frontal belt a succession of schists, slates, and metamorphic limestones, with extensive granitic intrusions of Paleozoic or Permo-Mesozoic age, extend southward for nearly 150 miles, but

[15] Op. cit., vol. 1, pt. 1, p. 138.

nothing older than the Cambro-Ordovician was noted. It is probable that similar conditions exist to the east and west of the Willis and Blackwelder traverse, in which event it is unlikely that the Algonkian is extensively represented.

EAST KAN-SU EXPOSURES

The west rim of the North Shen-si Basin was not visited, and the information at hand is insufficient to warrant definite conclusions as to the occurrence of Algonkian. Pronounced folding and faulting occur, however, and it is probable that formations of this age will eventually be discovered.

ORDOS EXPOSURES

Père Teilhard and Père E. Licent in a recent paper[16] report mica schists, quartzites, white marbles, and a few gneisses, which they correlate with the Wu-tai system, beneath folded sedimentary rocks in belts striking north 60 degrees to 70 degrees east (map), in the region just north of the great bend of the Hwang-ho.

CAMBRO-ORDOVICIAN

GENERAL CONDITIONS

The long period of Algonkian deposition, interrupted by periods of diastrophism, was followed by a further interval of sharp folding; then by a long period of erosion, during which the upturned beds were beveled and the surface reduced to a low relief. On the readvance of the sea, red shales, representing the finer residue of the weathered pre-Cambrian surface, were laid down locally, especially in the northeastern part of the North Shen-si Basin, while quartzites or freestones, representing the coarser products of rock decay, were deposited in the east, south, and possibly elsewhere. The occasional absence of the shale or quartzite seemingly points to the existence of local unsubmerged areas at this time.

Following the accumulation of the lagoon-deposited red shales and the littoral quartzites and freestones, subsidence was accelerated and marine conditions established, accompanied by the deposition of limestone, the accumulation of which continued, without interruption and with little variation of conditions, from late Lower Cambrian well into Ordovician time, ceasing only after 4,000 to 5,000 feet of limestone, designated the Ki-chou by Willis and Blackwelder, had been laid down in what may

[16] Observations Géologiques sur la Bordure Occidentale et Méridionale de l'Ordos, Bul. de la Société Géologique de France, 4th ser., vol. 24, p. 52.

almost be described as a single massive bed. Although usually possessing the thickness indicated, the accumulation seems to have been considerably less locally, owing to Archean or Algonkian elevations on the sea-bottom or to islands which, as in the case of the shales and quartzites, stood above sealevel throughout part or even the entire period of deposition.

MAN-TO SHALES

In eastern and central Shan-si, Willis and Blackwelder describe the Man-to formation as consisting of red shales, with some sandstone, one or two thin streaks of limestone, occasional beds of black or green shale, and sometimes a basal conglomerate, the whole having an approximate thickness of 200 to 350 feet. The age was regarded as "Middle and Late Lower Cambrian" on the basis of fossils which "occur within 100 feet above the (basal) contact" of the distinctive red formation of the Sinian System.[17]

A little red shale of the Man-to type was reported by Barnett between Ki-chou limestone and ancient schists at a point about 30 miles west of Tai-yuan-fu and again on the west side of a horst of probable Archean 20 miles east of the Hwang-ho, on Route 4 (figure 22). On Route 5 red shales were noted by Fuller in association with the Tung-chuan quartzite beneath the Ki-chou limestone on both sides of a faulted anticline, 2½ miles in breadth, at the town of Hsiang-yang-chen, 7 to 10 miles northwest of Fen-chou, on the Fen-ho plains (figure 23). Fifty feet of red shale were noted by Clapp at a basal Ki-chou horizon above the granite mass 20 miles northeast of Si-chou, on Route 7 (figure 25). The shales were not noted in association with the quartzite farther south in west Shan-si, but red and green shales occur with the San-yuen freestone, described below, in the vicinity of San-yuen, in central Shen-si.

TUNG-CHUAN QUARTZITE

On Route 3 (figure 21) Estabrook noted a cliff-making formation of pale pink semiquartzite on the northwest slope of the mountain northwest of Ching-lo-hsien, which he regarded as the equivalent of the Man-to or Tung-chuan. It dips westward under the Ki-chou limestone at an angle slightly greater than the slope, but reappears for some miles along the valley bottom near Ko-lan-hsien. Ascending the 7,000-foot range southwest of the city named, the quartzite disappears beneath the Ki-chou once more, but is found on both flanks of the Archean core and caps several of the highest summits above the pass. The quartzite is

[17] Op. cit., vol. 2, pp. 35 and 37.

here an incompletely cemented pink to red bed, and, although only gently warped as a whole, is locally much shattered. It is distinctly unconformable with the Archean gneiss.

A sandy series, consisting of (1) about 250 feet of basal fluvial sandstones resting unconformably on what was regarded as the Wu-tai Archean beds, (2) a shale zone 100 feet in thickness, separated from the foregoing by a disconformity, and (3) an upper eolian series of sandstones about 150 feet in thickness, resting conformably on the shales, has been reported by E. Norin[18] at two points on the west scarp of the Moerh-tung horst, in the northeast and southeast parts of Lin-hsien, in western Shan-si. The sediments "do not show the slightest trace of regional metamorphism" and appear to be followed conformably by the Cambrian limestone, although a disconformity is found in the sandy sediments some 25 feet below. The beds in question do not appear to have been noted by Barnett, who passed through the hsien, or district (Route 4), but whether Algonkian or Cambrian, they are almost certainly to be correlated with the Tung-chuan quartzite of the present paper.

The next quartzite exposures of importance noted at this horizon were on Route 5, where red quartzite and red shales were seen by Fuller beneath the Ki-chou limestone on both sides of a faulted anticline 2½ miles in width, at the town of Hsiang-yang-chen, 10 miles northwest of Fen-chou (figure 23). The shale is very thin or entirely absent in exposures to the south, as well as farther west, on Route 5, where a thickness of 500 feet or more of nearly pure pinkish quartzite was noted on the west side of the 3-mile-wide granitic mass 15 miles southeast of Yung-ning-chou, and again on both sides of a half-mile-wide granitic core two miles west of the preceding. The distinctive characteristics of these exposures led to the application of a separate formation name, taken from the Tung-chuan-ho, along the valley of which the outcrops occur.

On Route 6 (figure 24) Barnett observed quartzites lying on both sides of a 2-mile-wide uplift of granite and schist about 12 miles southwest of the outcrops southeast of Yung-ning-chou, on Route 5, with which they are probably connected. Five miles southwest of the exposures noted by Barnett, Fuller found the quartzite absent, with the Ki-chou apparently resting directly on the schists above the granite, but 5 miles farther south the quartzite shows beneath the limestone for a distance of a mile or more, with dips, possibly the result of faulting, as high as

[18] An Algonkian continental sedimentary formation in West Shansi. Bull. Geol. Soc. China, vol. 3, no. 1, pp. 55-72.

45 degrees in places. It is probable that several hundred feet of quartzite locally intervene between the Ki-chou limestone and the granite (figure 25) on the flanks of the uplift 20 miles northeast of Si-chou, on Route 7 (Clapp).

Clapp, on Route 9, found tilted quartzite beneath the Ki-chou limestone, in a fault-block on the west flank of the rugged 'O-shan (figure 29). On Route 10 the quartzites appear to be unrepresented.

Nothing that can be correlated with the Tung-chuan quartzite has been reported on the north or west sides of the North Shen-si Basin. On the south are the San-yuen freestones described below.

SAN-YUEN FREESTONES

"Freestones, quartzites, and associated red shales" were noted by Estabrook on the main road 5 to 10 miles north of San-yuen, a city 23 miles north of Si-an-fu, in central Shen-si, while 12 miles northwest of the first-named city light-colored freestones were found by Fuller in association with red sandstone, quartzite, and red and green shales, the outcrops having a breadth of 2 to 3 miles. The beds as a whole appear to dip under tilted Ki-chou limestone on the south and to be separated by faults from the Shan-si formation on the north. Freestone and millstone quarries were noted at several points.

The association of red and green shales with reddish sandstones is similar to that in the Man-to formation of Shan-si, while the quartzitic phase is suggestive of the Tung-chuan. The stratigraphic position of the freestones is in harmony with both, but the great distance from the type locality of either and the presence of freestone as a distinctive feature has led to the application of the name San-yuen, taken from the city near which the exposures are found. No other outcrops of a similar character were observed on the south rim of the North Shen-si Basin, the horizon, as a rule, being deeply buried by loess at its outcrop.

KI-CHOU LIMESTONE

Character and thickness.—This great limestone, 4,000 to 5,000 feet in thickness, forms the immediate rim of the North Shen-si Basin at nearly all points, since on it rest the lowest beds of the true basin filling, the Shan-si coal measures. It is of the type usually described as "blue limestone," although occasionally characterized by yellowish weathered surfaces resembling sandstone. Internally it is gray, brownish gray or buff color, sometimes mottled with white. Willis and Blackwelder, who gave it its name, state that it is without chert. It is normally hard,

dense, and compact in texture, effervescing freely with acid, but it is often finely oolitic toward the base. More rarely it is soft and granular, yellowish in color, and effervesces very slightly. Portions of the limestone are decidedly magnesian. The formation locally carries some gray or greenish shale in the lower 600 feet, with sometimes a little limestone conglomerate, but as a rule the upper 3,500 feet is all limestone. In some places the bedding is conspicuous, with the planes sufficiently close to give a sheeted appearance. Much of the limestone, however, is comparatively massive, with bedding planes rather widely spaced, and some outcrops are characterized by broad, smooth faces on which no traces of stratification are visible. Vertical jointing is well developed in places, but is often absent over considerable areas. Stratification lines other than bedding partings are seldom seen. Fossils are rare, but enough occur to establish the age of the formation. Caves, usually of the niche type, are found on the faces of the cliffs at a number of points, but caverns due to underground drainage are relatively rare and seldom of any size. Springs are not abundant, but several of considerable volume occur.

The variations in the thickness of the Ki-chou limestone resulting from the irregularity of the surface on which it was deposited, as well as from subsequent erosion of the upper portion, are very considerable. The extensive folding as well as the obscuring mantle of loess introduce great difficulties in the determination of comparative thicknesses in different localities. Several thousand feet are, however, commonly represented. In general, the thicknesses exposed in Shen-si are less than in Shan-si, but as the base is nowhere exposed it can not be stated that the actual thickness is any less. The same statement applies to the exposures noted among the west rim of the basin in Kan-su and to those reported in the northern Ordos. Along the Hwang-ho, on the eastern border of the latter, adjoining Shan-si, however, the Ki-chou occurs with practically its maximum thickness.

Stratigraphic relations.—The Ki-chou limestone rests conformably on the Tung-chuan quartzite where that formation is present, but where absent it rests directly on the Archean or Algonkian, masses of which appear to have locally remained above sealevel as islands throughout Tung-chuan and early Ki-chou deposition. In such localities the basal portions of the Ki-chou is necessarily missing.

An erosion unconformity also marks the contact between the Ki-chou and the overlying Shan-si formation. The Ki-chou surface exhibits in places the rounded characteristics of subareal erosion, while elsewhere

it shows clay stringers apparently representing soil-filled weathering fissures or passages resulting from water circulation. Iron ores and tufa-like deposits, probably incidental to the weathering, are also found. The uniformity of the horizon of the unconformity points to a surface of little relief as a whole, the inequalities seldom being more than a few hundred feet.

Age.—The deposition of the Ki-chou limestone began, according to

FIGURE 3.—*Typical Exposure of Ki-chou Limestone of the bedded Type*

The locality is in the Hwang-ho Canyon, 30 miles south of Ho-kou, on the east side of the Ordos (photograph by S. H. McClure).

Willis and Blackwelder, in late Lower Cambrian times and ceased at a date following the deposition of beds carrying a Trenton fauna, now found just below the Ki-chou-Shan-si unconformity.[19]

West Shan-si exposures.—While complexly folded and faulted, with local dips at all angles and in every direction, the Ki-chou limestone as

[19] Op. cit., vol. 2, p. 50.

a whole forms a series of nearly parallel and fairly continuous north-south belts through Shan-si from the northern border to the vicinity of Tai-ping, near which point they bend to the southwest, passing across the Hwang-ho into Shen-si near the mouth of the Fen-ho (figure 3).

Its structural elevation, due to folding and faulting, taken in connection with the fact that the limestone is much more resistant to erosion and weathering than the associated formations, causes it to stand out in striking topographic relief. It constitutes the topographic backbone of the 'O-shan (figure 4) and other high north-south mountain ranges of western Shan-si, the passes of which have altitudes up to 6,000 feet, with the summits probably rising from 2,000 to 4,000 feet higher in places.

Photographs taken by S. H. McClure (figure 3), who descended the Hwang-ho in a junk from the northern Ordos, apparently indicate that the Ki-chou forms the walls of the canyon of the river mentioned for the greater part of the way from the beginning of the southward bend to the intersection of Route 1. On this route Estabrook crossed a limestone belt about 40 miles wide, extending westward from the crystalline uplift. Structural details are now unavailable, beyond the fact that marked faults occur (figure 19). Beyond an intervening basin of Shan-si coal measures 10 miles in width the limestone reappears in a belt some 3 miles in breadth at the sharp elbow of the Hwang-ho 12 miles east

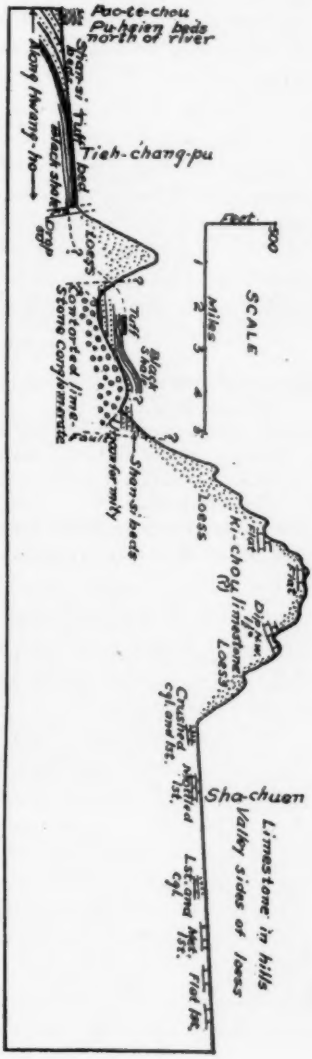

FIGURE 4.—*Section extending eastward along Route 2 from the Hwang-ho at Pau-te chou (Clapp)*

of Ho-che-hsien. The limestone is chiefly Ki-chou, but some Algonkian may possibly be present.

Where crossed by Clapp on Route 2 the limestone, except for two loess-hidden stretches of 5 or 6 miles in width, was found to outcrop at short intervals along the valley bottom for a distance of 50 to 60 miles, with the mountains beyond the loess on both sides apparently of the same material (figure 20). For the most part the beds were flat-lying. The upper portion of the limestone, including several thousand feet of the formation, is of the normal Ki-chou type, but some of the valley exposures exhibit Algonkian characteristics. Thus, at two points, 2 and 4 miles southeast of San-cha, 35 miles east of Pau-te-chou, a metamorphic limestone associated with quartzite and conglomerates was encountered (figure 20). A similar metamorphic limestone, also with conglomerate, was noted east of Sha-chuen, 18 to 20 miles east of Pau-te-chou (figure 4), while 2 miles west of the village the following section was observed:

Section near Sha-chuen

	Feet
Recent conglomerate (cemented stream gravels)	20
Unconformity.	
Coarse conglomerate, with pebbles of limestone, quartzite, and jasper, probably derived in part from the Nan-tai or other beds of the Wu-tai system	10
Unconformity.	
Light gray limestone, much crushed, with calcite veins	10
Pink quartzite	2

A few miles farther west and some 3 miles from the Hwang-ho, a highly contorted conglomerate of pink and gray limestone pebbles, of an appearance similar to the preceding exposures, was found beneath the Shan-si coal measures, from which it is separated by an erosion unconformity (figure 4).

The metamorphism, crushing, presence of jasper pebbles, and the associated quartzite are features which are common in Algonkian formations, and the position of the older valley outcrops east of Sha-chuen suggests an Algonkian surface beneath the basal Ki-chou. Near the Hwang-ho, on the west, however, beds of similar Algonkian aspect are found beneath the Shan-si formation at a horizon several thousand feet higher. The supposition of an unconformity of this magnitude involves the persistence of a limestone scarp without material recession through several periods of advanced erosion or peneplanation from the Algonkian to the present time, since the Ki-chou is still found at altitudes of 1,000 to 1,500 feet or more above the coal measures in the immediate vicinity.

Such a hypothesis is manifestly untenable, and the writers are forced to the conclusion that notwithstanding their similarity of characteristics there are two widely separated horizons of crushed or contorted rock of ancient aspect. The easternmost is probably lower Ki-chou, although there is a possibility that it is Algonkian. The westernmost exposures, consisting of contorted limestone conglomerate, is apparently an upper Ki-chou horizon lying on the downthrow side of an important fault. No beds of similar character were observed elsewhere at this horizon or were noted by Willis and Blackwelder in their detailed studies elsewhere in Shan-si. Although the Ki-chou is sometimes shattered or contorted in other places, the disturbance is of a post-Carboniferous date. Since the overlying Shan-si beds are unaffected at the point under consideration, the disturbance here, if connected with the great fault lying immediately to the east, can only have resulted from pre-Carboniferous movements, probably of small magnitude compared with that shown by the present throw.

On Route 3 Estabrook reported a belt of folded Ki-chou limestone 9 miles wide on the west flank of an Archean mountain mass 30 miles west of the valley north of Tai-yuan-fu (figure 21). The contact with the crystalline rocks, as is often the case elsewhere, was deeply covered with loess. The Ki-chou should be represented, probably in a downthrown fault-block, west of the basin of Shan-si and Pu-hsien beds near Ching-lo-hsien, but the region is deeply loess-covered. The limestone is found, however, on the west side of the mountain a few miles farther to the northwest, and apparently extends in a broad trough with gentle dips to the next mountain mass southwest of Ko-lan-chou, a distance of 30 miles or more. Near Ko-lan-chou, only the underlying Tung-chuan is exposed in the valley, but cliffs high on the surrounding mountains and abundant limestone pebbles in the streams seem to substitute the continuity of the Ki-chou in the uplands, as assumed. The limestone is also strongly developed on the west side of the westerly range, dipping under the Shan-si formation at its west base.

On Route 4, traversed by Barnett, the Ki-chou shows for 2 miles at the west border of the main Fen-ho plain west of Tai-yuan-fu, where it is overlain by Shan-si coal measures on the west (figure 22). Ten miles northwest of the preceding it is exposed beneath the Shan-si on the axis of an anticline some 2 miles in width, showing at the bottom of the upper Fen-ho Valley. Fifteen miles west of the second exposure it is found dipping eastward away from the Tai-shan complex, from which it is separated by a slight thickness of red Man-to shale. On the west side

of the complex, here about 50 miles in breadth, only a slight thickness of limestone was recorded, while none was noted on either side of a 4-mile-wide complex crossed 20 miles northwest of the last and about midway between it and the Hwang-ho, although it is possibly present beneath the loess-covered flanks.

Fuller, on Route 5, found the Ki-chou limestone above the Tung-chuan quartzite and Man-to shale on both sides of an anticline about 10 miles northwest of Fen-chou (figure 23). The strike was approximately north 60 degrees east, with dips of 20 degrees on the southeast and 12 degrees on the northwest. On the latter side the limestone continues to show in a syncline with gentle rolls and minor faults for over 10 miles, then arches up over an Archean complex 3½ miles in width at a point 15 miles southeast of Yung-ning-chou. On the west side of this mass the limestone dips away from the granite and intervening Tung-chuan quartzite at angles of 15 to 25 degrees, but 2 miles farther west stands vertically against the quartzite on the flanks of another half-mile-wide granite uplift. Beyond the latter the limestone outcrops with prevailingly westerly dips of 15 to 20 degrees until it disappears under thick loess 5 miles east of Yung-ning-chou, probably passing beneath Shan-si coal measures. Four miles southwest of the city, Barnett reported a limited thickness of limestone between Shan-si measures and a granite and schist complex 3 miles in width, on the farther or west side of which the limestone shows in a belt 6 or 7 miles in width before dipping gently under the Shan-si beds at a point approximately 10 miles east of the Hwang-ho.

On Route 6 (Fuller and Barnett) the Ki-chou rises from beneath Shan-si beds at a point 15 miles west and 7 miles south of Fen-chou (figure 24), continuing northwestward in rolling faulted folds with dips commonly from 5 to 15 degrees, but locally increasing to 40 or 65 degrees, for a distance of 15 miles before rising above the Tung-chuan quartzite flanking a granite and schist uplift 3 to 4 miles in width, situated 15 miles south and a little east of Yung-ning-chou. At a second crossing of the same uplift a few miles to the southwest, not repeated in the section, the quartzite appeared to be absent, with the limestone resting on the schist. On the northwest of the uplift, off the line of the traverse, the limestone, the outcrop of which is about 3 miles in breadth, sinks beneath the Shan-si coal measures. Six miles to the southwest of the second crossing of the uplift and on line of section, the limestone is arched and faulted over a narrow quartzite core. The limestone finally disappears beneath the loess, probably passing beneath the Shan-si, 4 miles west of the quartzite.

Clapp, on Route 7, found the Ki-chou rising from beneath the Shan-si coal measures 25 to 30 miles southwest of Fen-chou (figure 25), the limestone continuing to outcrop in rolling folds across the mountainous belt to the southwest for a distance of nearly 30 miles. The dips are ordinarily from 5 to 20 degrees, but locally reach 45 degrees or more. The limestone near its southwest limit is arched over a granite core, the two being probably separated locally by Man-to shale and Tung-chuan quartzite. The contact with the overlying beds to the west is hidden by loess. Some of the limestone is of older appearance than is usual in the Ki-chou.

Between a point 10 miles northwest of Hung-tung on the Fen-ho and another point 20 miles to the west, the latter about 10 miles east of Pu-hsien, Fuller found four areas of limestone, probably Ki-chou, appearing between basins of Shan-si bed (figure 26). From east to west the limestone outcrops had breadths of 2, 4, 4, and 5 miles respectively. The first seems to be an anticline with dips of from 10 to 30 degrees. The second, separated from the preceding by a basin of Shan-si beds a mile or so in width, is marked by several folds with dips of 10 to 20 degrees. The third appears to be bounded on the east by a fault, but on the west dips beneath Shan-si beds. Its outcrop shows distinct folding. The fourth seems to rise from beneath Shan-si measures with dips of about 5 degrees on the east, but is tilted to a vertical position, probably against a fault, on the west. The dips of the limestone, except near the fault, are usually in an easterly direction at angles of 5 to 10 degrees.

Route 9 crosses the great 'O-shan (figure 27). The Ki-chou limestone, according to Clapp, begins at a fault at the edge of the Fen-ho Valley and extends in broad folds for a distance of 25 miles, interrupted only by a local basin of Shan-si beds, 5 miles in width, occupying the limestone syncline at the summit of the mountain, at 4,600 feet. West of the crest the folding becomes sharper, and at the western edge of the uplift the limestone, with the underlying Tung-chuan quartzite, is tilted eastward in two or more fault-blocks, against the westernmost of which the Shan-si appears to be locally upturned. Part of the limestone is of Algonkian aspect.

A limestone belt more than 2 miles in width was noted by Fuller on the northwest side of a granite mass on Route 10 (figure 28). The lower part is cherty and possibly Algonkian in age. The upper part, which is cut by faults and tilted at angles of from 50 to 90 degrees in places, is presumably Ki-chou and is overlain by steeply dipping Shan-si beds.

Central Shen-si exposures.—For a distance of 50 miles southwestward across Shen-si, from the point where the Ki-chou was last noted, in the angle between the Hwang-ho and the Fen-ho, Shan-si, the limestone is hidden beneath a high and comparatively slightly dissected loess plateau along all of the routes traversed. The first indication of the possible presence of the Ki-chou was found west of the Lo-ho, 25 miles northwest of Tung-chou-fu or Ta-li, where Estabrook reported a "loess ridge probably underlain by Sinian" rising above the general level of the loess plateau.

In the valleys of the larger streams between San-yuen and I-chun, north of the Si-an-fu, the Ki-chou limestone was noted by several geologists, usually in association with Shan-si coal measures, in upthrown fault-blocks at three localities (figure 5). The southernmost, near the crossing of the Çhe-ho at Yao-chou, 18 miles north of San-yuen, shows beneath thick loess as a narrow southward-tilted mass bounded on the north by a fault. The second, 7 miles farther north, is of similar character, but with Shan-si measures resting against its faulted northern edge. North of the coal measures, which have a width of about 2 miles, is the third area of Ki-chou, having a width of about 4 miles. Its southerly contact with the Shan-si is marked by a fault, but on the north it apparently dips under the formation mentioned. Several pronounced faults are found within the limestone area.

Farther west the Ki-chou is seen along the northern tributaries of the Wei-ho, as follows: (1) In association with San-yuen freestones, dipping 35 degrees to the south, in faulted masses with green sandstones on the north, at a point 15 miles northwest of San-yuen; (2) as a tilted mass dipping north from 11 to 25 degrees, under heavy loess, 3 miles northwest of Kien-chou; (3) as a mass with strong variable dips 7 miles east of Feng-siang-fu; and (4) in a tilted mass beneath thick loess, with westerly dips of 35 degrees or more, 10 miles northeast of Feng-siang-fu.

While not seen *in situ*, pebbles in Cretaceous and later gravels in the region of Lung-chou, in the extreme western part of Shen-si, seemingly point to the presence of Ki-chou in mountains to the southwest and northwest, suggesting a northward swing of the formation to form the western rim of the North Shen-si Basin.

East Kan-su exposures.—The only point at which limestone was actually seen along the western rim of the basin was near Ping-yuan, where tilted limestones, presumably the western representatives of the Ki-chou, form a horseshoe-shaped ring inclosing the city and local desert. Deep loess hid the flanking beds where the limestone was crossed.

Ordos exposures.—The Ki-chou is strongly represented along the Hwang-ho at the Shan-si border on the east side of the Ordos, as mentioned under "West Shan-si." It also probably occurs in narrow, sharply folded and faulted belts with a general east-west trend in the region north of the great bend of the Hwang-ho around the north edge of the Ordos.

FIGURE 5.—*Section from Tsin-ling-shan northward across the Wei-ho Valley to Tung-kwan-hsien. (Estabrook)*

The lower and upper Fen-ho plains occupy grabens which C. C. Wang has called "Ping Yang graben" and "Tai Yuan graben" in "An outline of the geological structure of Shen-si," in Bulletin Geological Society, China, volume IV, number 1, 1925, pages 67 to 80. The presence of these graben was noted by Richtofen and Willis.

MIDDLE PALEOZOIC

The long period of limestone accumulation represented by the Ki-chou formation was eventually brought to a close. In southern Shen-si, outside the limits of the North Shen-si Basin, Willis and Blackwelder found 1,800 feet of gray, green, and black shales (Sintan formation) representing "all of the Silurian (Gothlandian), Devonian, and Lower Carboniferous time."[20] In the region under discussion the time of the cessation of deposition can not be fixed. It is possible that accumulation continued after the deposition of the uppermost of the present Ki-choü beds, as in the more southerly region, but it seems unlikely that had there been such deposits they would have been everywhere removed without leaving at least a trace. On the whole, it seems probable that they were never deposited within the area of the North Shen-si Basin, but that, following an epeirogenic movement inaugurated, according to Willis and Blackwelder,[21] in the Trenton period, the deposition of limestone ceased and the beds were subjected first to marine scour and subsequently, at an undetermined period, to

[20] Op. cit., vol. 2, p. 55.
[21] Op. cit., vol. 2, p. 50.

moderate uplift and erosion. The resulting surface, represented by the Ki-chou-Shan-si unconformity, has been described in the section on the Ki-chou limestone. The uniformity of its horizon, which, according to the authorities quoted, is just above the Trenton fauna, points to a surface of little relief as a whole, although monadnocks almost certainly existed. The thickness of limestone removed is not believed to have been great.

Permo-Carboniferous

General conditions

Following the early Carboniferous uplift a subsidence brought the Ki-chou limestone within reach of the waves, by which the residual soils were removed. On the bared rocks were then laid down a series of shore and marsh deposits, including sandstones, shales, thin limestones, and coals carrying plant or invertebrate remains which establish the age of at least the lower beds as Pennsylvanian. The deposition of typical coal measures beds continued without important change in character until 300 to 1,000 feet had accumulated, although fossil plants appear to indicate that the upper portion is Permian in age. In the North Shen-si Basin there appears to be nothing equivalent to the great Wu-shan Upper Carboniferous limestone, 3,000 feet in thickness, found in the Yang-tze-kiang gorges.[22]

Shan-si formation

Name.—Willis and Blackwelder write: "Under the term Shan-si we include the coal-bearing strata, which are so characteristic of Shan-si, and also the red sandstones, which overlie the coal measures in apparent conformity."[23] On their general map of the Shan-si region (Volume 2, plate 1), however, the red sandstones and shales are mapped as "Red Beds" and classed as Permo-Mesozoic, while the term Shan-si is applied to the coal measures alone. Since the name is thus used in two distinctly different senses, and as the latter more restricted application appears more likely to represent final conclusions and to be preferred to that of the definition, which includes under a single term rocks of entirely dissimilar characteristics, the writers have followed the map usage and applied the term to the beds of similar character and the same stratigraphic position found around the edge of the North Shen-si Basin.

The China Geological Survey,[24] following an examination of the coal

[22] Willis and Blackwelder: Op. cit., vol. 2, p. 71 et seq.

[23] Loc. cit., vol. 1, pt. 1, p. 148.

[24] The late Paleozoic and early Mesozoic sediments of central Shan-si, by E. Norin. Bull. Geol. Surv. of China, no. 4, October, 1922, pp. 3-80.

fields near Tai-yuan-fu, Shan-si, in 1921, substituted the name Yueh-men-kou for Shan-si as the designation of the coal measures of Willis and Blackwelder, restricting the latter name to the upper of the two divisions in which it now separated the original formation, to the lower of which the term Tai-yuan was applied. There seems to be no adequate reason for substituing the new for the older name of the formation as a whole, which is the only convenient lithological unit which can be recognized over any considerable area. The new use of the term Shan-si is still more to be deplored as not only ignoring priority, but introducing an unnecessary source of confusion. In the present paper the term Shan-si is used in its original sense, as applied on the maps of Willis and Blackwelder.

Character and thickness.—In central Shan-si the Shan-si formation ordinarily has a thickness varying from 300 to 1,000 feet, depending on the nature of the basal unconformity. Locally the formation is entirely absent, with Pu-hsien beds resting against the Ki-chou limestone. Faulting doubtless accounts for the relation mentioned in places, but elsewhere it is probable that the Ki-chou remained above water during the entire Shan-si stage and prevented the accumulation of deposits of that age.

In Shan-si, where fully developed, the Shan-si formation consists of a basal division of alternating sandstones and gray or brown shales with little limestone, a middle section of black shales, pyrite beds weathering into limonite, several thin limestones, some sandstones, and numerous thick coals, and an upper division of yellowish to brownish sandstones with comparatively little shale or limestone and only thin streaks of coal. Correlations with the subdivisions of the China Geological Survey are given below:

Divisions of Shan-si Formation

	China Survey Divisions		Age
Shan-si	Upper Division	Basal Shih-ho-tse.....	Permian.
		Shan-si (restricted).....	Permo-Carboniferous.
	Middle Division	Disconformity.	
	Basal Division	Upper Tai-yuan.....	"Lower Carboniferous."
		Lower Tai-yuan.....	"Lower Carboniferous."

The middle, or coal-bearing, division near Tai-yuan-fu has been further divided by the Survey mentioned in a large number of local formations, but these appear to continue for only short distances and to be of only local interest. Twelve coals are recognized, five below and seven above the disconformity. The coals east of Tai-yuan-fu are chiefly

anthracitic; those on the west are largely bituminous. The thickest of the anthracite coals are numbers III, IV, and V; of bituminous, numbers VIII to XII. At the outcrops near Tai-yuan-fu the coals are usually under 5 or 6 feet in thickness, but in some of the mines they thicken to 15 or 18 feet. Near Pau-te-chou, on the Hwang-ho, in northwest Shan-si, a bed from 36 to 67 feet in thickness has been reported.[25] The total tonnage of the coals has been discussed by the writers in another paper.[26]

Passing into Shen-si, there is a marked change in the character of the rocks of the Shan-si formation, the materials from which they were derived apparently coming from the south instead of from the east, as in Shan-si. Although there are still some shales and a few coals, the formation as a whole is practically without limestones and decidedly more sandy, with considerable thicknesses of coarse green, often cross-bedded, sandstone, quite different from the buff sandstones of Shan-si. The total thickness of the formation in the east is probably about the same as in Shan-si, but the sandstones appear to thicken on approaching the Kan-su line, where possibly 2,000 feet of sandstones and shales, with several coals, are present in the vicinity of Lung-chou, near the head of the Wei-ho. It should be noted, however, that the red beds of the Pu-hsien formation, which immediately overlie the coal-bearing measures in Shan-si, seem to disappear in western Shen-si, making it difficult to fix the upper limits of the formation with certainty.

The western rim of the North Shen-si Basin in Kan-su was touched only at Ping-yuan, and near Ling-chou, 65 miles farther north. At the former the Shan-si, if present on the flanks of the upturned Kichou (?) limestone, is buried where crossed by 1,500 feet or more of loess. Between the two cities and east of the second the exposures of probable Shan-si beds indicate a character similar to that of the beds of the same age on the south side.

Stratigraphic relations.—The Shan-si formation often abuts against fault-planes at its contact with the Ki-chou limestone, but where found in its normal relations it rests unconformably on the limestone, which in the long interval lasting through the Devonian and early Carboniferous was slightly lifted, with little or no tilting, and exposed to erosion. In general the relief did not exceed a few hundred feet, but the occasional absence of the Shan-si suggests the existence of greater elevations, although in many cases its non-representation is probably to be attributed to faulting.

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[25] C. C. Wang: Bull. Geol. Surv. of China, no 4, October, 1922, pp. 107-118.

[26] Revision of coal estimates for West Shan-si, China. Econ. Geol., vol. 21, pp. 743-756.

Throughout the province of Shan-si the Shan-si beds appear to be followed conformably by the Pu-hsien, the change seemingly being one of gradual transition, with the red color characteristic of the latter appearing first as a few thin streaks and gradually increasing until it is the most distinctive feature of the formation. In western Shen-si, where the red color of the Pu-hsien disappears, the formations may be regarded as practically continuous.

Age.—The coal-bearing measures of the Shan-si series in Shan-si were placed by Willis and Blackwelder in the "Upper Carboniferous" (Pennsylvanian).[27] More detailed studies by members of the China Geological Survey show the original Shan-si to be divided into "two distinct series, separated by a disconformity and a pronounced hiatus." The basal division is referred to as of "late *Dinantian* age" and elsewhere as "Lower Carboniferous." The upper part, which contains many of the principal coals, is referred to the Permo-Carboniferous.[28]

West Shan-si exposures.—The most northerly point at which the Shan-si formation was noted was on Route 1 (figure 19), where Estabrook found low-dipping Shan-si beds with coals in a basin, 9 miles broad, between Ki-chou limestone masses. The easterly contact, a fault-plane, is 12 miles east of the Hwang-ho, at the sharp elbow 13 miles east of Ho-che-hsien, while the westerly contact, probably the normal unconformity, lies 2 miles east of the bend. West of the narrow westerly limestone belt, which crosses the river at the bend mentioned, the Shan-si measures dip away from faults at or near the contact into the North Shen-si Basin, exhibiting a number of folds with dips averaging about 5 degrees, but sometimes rising to 20 degrees.

On Route 2 Clapp found the Shan-si measures resting unconformably on a limestone conglomerate, probably belonging to the Ki-chou, at several points about 7 miles east and a little north of Pau-te-chou (figures 5 and 20). Above a basal sandstone and a series of black shales a bed of red tuff and a white porcelainite-like stratum several feet in thickness was traced for several miles. Numerous coals, some reaching thicknesses of 35 to 65 feet, are worked in the Pau-te-chou region. A fireclay furnishes material for extensive pottery at Pau-te-chou. The beds near the Hwang-ho are much faulted and folded, with dips of from 5 to 60 degrees.

A belt of dark to yellowish shales, about a mile in width, was reported by Estabrook on Route 3, between the Ki-chou and Pu-hsien formations 5 miles east of Ching-lo-hsien (figure 21). An outcrop of Shan-si beds

[27] Op. cit., vol. 2, p. 71.
[28] E. Norin: Op. cit.

some miles in width, between Ki-chou limestone and Pu-hsien beds, was crossed at a point nearly due south of Pau-te-chou, the dip being westward into the North Shen-si Basin.

Barnett recorded Shan-si measures with numerous workable coals between uplifts of Ki-chou limestone on Route 4, beginning about 10 miles west of Tai-yuan-fu and extending for nearly 25 miles (figure 22). The beds lie in wavy folds above the limestone, with dips seldom exceeding 5 or 10 degrees and with little faulting. Shan-si beds also apparently occupy a basin some 15 miles in width between Archean uplifts at Lin-hsien, 25 miles east of the Hwang-ho. Shan-si measures do not appear to have been recognized to the west of the westernmost Archean area, midway between the city and river named, but may outcrop beneath the loess.

Nothing above the Ki-chou was actually seen east of Yung-ning-hsien on Route 5, but Shan-si beds probably occur beneath the thick loess east of the city (figure 23). Three miles southwest of the town Barnett crossed a small basin of Shan-si coal measures overlain by Pu-hsien beds, the westerly contact with Ki-chou limestone being along a fault-plane. The Shan-si beds in nearly their full thickness dip westward between the Ki-chou and Pu-hsien, on the farther side of the granite and limestone uplift 15 miles east of the Hwang-ho.

On Route 6 coal measures were encountered near the edge of the Fen-ho plains, 15 miles southwest of Fen-chou, and were followed in a northwesterly direction for 10 miles by Barnett (figure 24). The outcrop, which is marked by prevailingly easterly dips, interrupted by folds with dips of 2 to 15 degrees, lies on the east flank of a broad area of Ki-chou limestone. The Shan-si is not represented near any of the uplifts of granite, schist, quartzite, or limestone in the next 30 miles to the west. Deep loess covers the region immediately west of the westernmost outcrop of the Ki-chou for several miles. Beyond, although gray or buff shales show occasionally between exposures of reddish rocks, they are probably to be referred to the Pu-hsien.

Clapp, on Route 7, found a belt of coal measures extending southwestward from the edge of the Fen-ho Plain, near Route 6, for 20 miles (figure 25). The prevailing inclination is easterly, as on the latter route, but folding is more pronounced, the dips frequently being as high as 15 degrees and increasing to 40 degrees near the Ki-chou limestone, the contact with which was hidden by loess. Again, as on Route 6, the nearest beds to the Ki-chou on the west side of the broad uplift were red in color, resembling the Pu-hsien. There is a strong likelihood that the

Shan-si is here absent because of non-deposition, resulting from the relief of the surface represented by the underlying unconformity.

On Route 8 Fuller found three small areas of dark shales with workable coals in troughs in a limestone supposed to be the Ki-chou, but possibly Shan-si, at points 8, 10, and 15 miles northwest of Hung-tung (figure 26). West of the last of the three areas, beyond an intervening mass of Ki-chou 3 miles in width, is an 8-mile-wide basin containing an unusual thickness of Shan-si beds, including dark, yellowish, or greenish shales, sandstones, thin limestones, and coals, with traces of red near the top. Folding is pronounced with dips of 10 to 20 degrees. The beds rest on the Ki-chou limestone on both the east and west. Beyond the westerly limestone, the outcrop of which is 3 to 4 miles in width, the Shan-si coal measures lie in a sharp anticline, with dips of 45 to 60 degrees against a fault contact, and are overlain on the west by Pu-hsien beds. The outcrop is 55 to 60 miles east of the Hwang-ho.

Fifty miles east of the Hwang-ho, on Route 9, Clapp found Shan-si measures in a trough, 5 miles in width, in the Ki-chou limestone at the crest of the high 'O-shan, at an altitude of 4,600 feet, but on the west side of the mountain mass the Shan-si was depressed by faulting, leaving sharply folded Pu-hsien beds resting against the limestone, from which it is separated by a fault (figure 27). Large coal mines are, however, reported "near Hsiang-ning," in the vicinity, in one of which the seam has a thickness of 15 feet; hence it is certain that the absence of the Shan-si beds is only local.

On Route 10 (figure 28) Shan-si measures with coals, several of which are worked, occur in the walls of the Hwang-ho canyon or in tributary ravines, from the water level to an altitude of 1,200 feet above the stream; but since there is a general dip toward the river, reaching as high as 35 degrees near the contact with the underlying limestone, the actual thickness, notwithstanding several reversals of dip, is probably considerably less than might at first appear. Four hundred feet of horizontal Shan-si strata were, however, exposed in a single outcrop in one of the ravines. The formation rests, with little or no discordance of dip, on the Ki-chou limestone, which with a lower cherty limestone, possibly Algonkian, overlies a large mass of red granite. Black and gray shales predominate in the Shan-si exposures, with pyrite beds, an occasional thin limestone, and a little sandstone. Traces of red shale occur. The thickest coal noted measured about 15 feet. The Shan-si beds outcrop northward along the Hwang-ho for 15 miles or more before disappearing under the Pu-hsien formation at a point 25 to 30 miles north of the mouth of the Fen-ho.

Central Shen-si exposures.—Westward from the Hwang-ho, in the canyon of which, as just noted, the Shan-si beds are exposed for many miles, the outcrop of the formation lies beneath a broad loess plateau with its crest over 1,000 feet above the stream named. Even the valley of the Lo-ho, with bottom 800 feet below the level of the loess plain, did not reach the rock at the point where it was crossed.

The first exposure of the Shan-si formation to be seen was 25 miles southeast of I-chun and 50 miles west of the Hwang-ho, where flat-lying beds of dark shale and cross-bedded sandstones were seen in a ravine in the loess, while coal was reported 2 miles to the south. The cross-bedding, which is common from this point westward, represents a change of conditions from those existing along the basin rim in Shan-si, where the bedding is usually regular.

The next exposures seen to the west were on the east road, between Yao-chow and Tung-kwan-hsien (figure 5). The Shan-si beds, with coal mines, are found on a downthrown fault-block about 2 miles across between uplifted blocks of Ki-chou limestone about 7 miles south of the last named city and about 50 miles north of Si-an-fu. Similar beds, also with bituminous mines, are found above the Ki-chou limestone in a graben basin 5 miles in width at the city of Tung-kwan-hsien. A little of the overlying Pu-hsien red shales show in the center. The Shan-si formation is cut off by a fault on the north. The southern outcrop of the Shan-si beds in the basin has a width of three miles and the northern about one mile. The formation is much more sandy than in Shan-si, with coarse greenish sandstones, often cross-bedded, predominating over the shales, which are usually weakly developed. The coal is said to be friable and dirty.

Fifteen miles northwest of San-yuen coarse green sandstones of the Shan-si type were noted on the north side of folded and faulted masses of Ki-chou limestone and San-yuen freestone. The beds are exposed with dips up to 3 degrees for about 6 miles in an east-west direction along a creek bed.

To the westward of the last exposure everything is deeply buried beneath a loess plateau for 15 or 20 miles, ravines from 600 to 800 feet in depth failing to cut into the rocks. At a point 17 miles west and 6 miles north of the preceding exposure, however, coarse green sandstones, probably belonging to the Shan-si formation, were seen along the banks of two streams, the beds of which were a thousand feet below the plateau level. The points were 4 miles apart in a northeast-southwest direction and probably point to rapidly increasing thicknesses to the westward. No coals were noted.

Beyond another fifteen-mile stretch of loess plateau a few sandstones, probably of the Shan-si formation, are seen in the valley at Yung-shou, where northerly dips of 7 degrees were noted. Shales and sandstones with southerly dips of 2 to 15 degrees and northerly dips up to 5 degrees are found 7 to 10 miles north of Yung-shou, about half way to Pin-chou-hsien, and also along the Ma-lien-ho for a distance of 5 or 6 miles immediately east of that city. They carry, so far as known, no coals and may belong to formations above the Shan-si.

Just north of Lin-yu, 17 miles southwest of Yung-shou, exposures of coarse green, sometimes cross-bedded, sandstones, alternating with purplish shales with northerly dips of 5 degrees, are seen at the bottom of a creek bed. In a southwesterly direction similar beds are found in the bottoms of ravines cut to depths of over 1,000 feet in the loess for a distance of 20 miles. Near Lin-yu the beds are mainly coarse green sandstones with a little purple shale, but to the southwest there is considerable dark shale with a slight purplish tinge, and in the basal portion, above the contact with the Ki-chou limestone, 7 miles northeast of the large city of Feng-siang-fu, there is a bed of "tufflike" red shale. No coal was seen. The dips are mainly north or northwest and decrease from 20 to 30 degrees near the limestone to 3 to 7 degrees near Lin-yu. The beds are believed to belong to the Shan-si formation and to be repeated by warping and possible faulting.

Massive green sandstone and conglomerate, probably of the Shan-si formation, are found on the northwest flank of a sharp anticline of Ki-chou limestone 10 miles northwest of Feng-siang-fu.

The most westerly point at which the Shan-si series was noted was near Lung-chou, near the Kan-su line, where green sandstones with shales and coals, some of which are mined on a small scale, are exposed in the bed of the Kien-shui 5 miles southeast of the city; thence along the river for 8 miles farther in the same direction. At the northwesterly exposures the dips are 1 to 3 degrees to the northwest, but in the central (coal-bearing) and southeasterly exposures they range from 25 to 45 degrees, or even 90 degrees at one point.

It is not unlikely that all exposures of the Shan-si formation west of Tung-kwan-hsien should be considered as lying in the belt of sharp folds and grabens surrounding the North Shen-si Basin rather than in the undisturbed basin. The exposures apparently indicate a far greater thickness of the formation than is found in Shan-si, although much of the apparent thickness may be due to repetition of the beds by faulting or folding or to the inclusion in the Shan-si of a part or the whole of the

non-red Pu-hsien or its western equivalent. A thickness of 2,000 feet, however, is not impossible in this region.

Kan-su exposures.—Between points 12 and 20 miles east of Ling-chou, in northeastern Kan-su, a belt of strongly folded and faulted green sandstones with local shales, limestones, and workable coals, about 8 miles in width, was crossed by Fuller, who correlated the beds with those of the Shan-si formation on the east and south sides of the North Shen-si Basin. The relations to other formations were obscured by desert gravel and sands. Dips were seldom less than 10 degrees and were frequently from 20 to 30 degrees. The total thickness of the formation would appear to be several thousand feet.

The same or a similar belt was crossed about 25 miles southwest of the first exposures, at a point about midway between Ling-chou and Ping-yang. The coals are worked at several points. Dips are as high as 60 degrees in places.

Where the limestone mass encircling Ping-yang was crossed, thick loess covered all flanking beds and nothing was seen of the Shan-si.

The coals of the region, usually reported as from Ning-shia, but probably from the exposures described above or from reported exposures "at the base of the Ala-shan" a few miles to the west, are described by A. C. Sowerby[29] as heavy and dirty but smokeless, continuing to burn, when once ignited, with a dull glow, smouldering like charcoal until reduced to a soft white ash—a description suggestive of an anthracite. The coal has at times been rather widely distributed by mule trains throughout the surrounding regions, but the mines did not appear to be working when the region was traversed in 1914. The aggregate thickness of the coals is not great.

Carboniferous shales and sandstones, with coal mines, are mentioned or shown in section by P. L. Yuan[30] near Ping-liang, about 70 miles southwest of King-yang, Kan-su, and 40 miles north and a little west of Lung-chou, Shen-si, the nearest points visited by Fuller. Farther west marine or continental Carboniferous deposits are known at numerous points in the Nan-shan region of western and northwestern Kan-su, but they are mainly well outside the rim of the North Shen-si Basin.

Ordos exposures.—Carboniferous beds are supposed to occur in the folded series on both sides of the northward-flowing Hwang-ho north of the northeastern tip of Kan-su in general line of strike with those seen by Fuller near Ling-chou. They are also reported on the flanks of the

[29] Through Shên-kan. London, 1912, p. 123.

[30] Ordovician graptolite beds of Ping-liang, East Kansu. Bull. Geol. Soc. China, vol. 4, no. 1, 1925, pp. 19-20.

Ala-shan west of Ning-shia, Kan-su. They do not appear to have been identified on the south side of the Hwang-ho at the great north bend, but probably occur in the strongly folded ridges beyond the rim of the basin on the north side of the river.

PERMO-TRIASSIC (?)

GENERAL STATEMENT

The use of the term Permo-Triassic is to be questioned, as it bridges a gap in which notable unconformities are proven elsewhere in the world; yet it has been used in the past, and is used here in the same sense, questioned.

The early Mesozoic was marked by a general uplift, a decided broadening of the existing lands, and a corresponding shrinking of the ocean areas. The warping which accompanied the uplift left a number of embayments, including that here known as the North Shen-si Basin, which may have been partially connected at times with the open sea, as well as smaller continental basins without such connection.

The change of conditions took place very gradually, probably soon after the close of the Shan-si deposition, as the later formations are not of general distribution, but are restricted to the basins. There is no sharp lithologic break, however, the older beds merging into the younger by gradual transition.

The high feldspathic content of the Permo-Triassic in western Shan-si and adjoining portions of eastern Shen-si indicates the existence of Archean and Algonkian landmasses.

The severe compression folding around the rim of the North Shan-si Basin was chiefly subsequent to the Permo-Triassic, since Pu-hsien beds are involved with it in Shan-si, while the lower Shen-si beds are likewise affected in central Shen-si, although to a less extent.[31] Some of the Mesozoic eruptives may be as early as Triassic, but the greater part are of a later age.

Since marine fossils are unknown, it is probable that the North Shen-si Basin was disconnected from the ocean through a part of Permo-Triassic times at least.

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[31] This view is necessarily dependent upon the correctness of the assignment of the Pu-hsien beds to the Permo-Triassic by the China Geological Survey. That the disturbances began somewhat earlier in regions only a short distance to the east appears to be indicated by the occurrence of beds indentified as Liassic by Richthofen in unconformable contact with the Sinian (Ki-chou) limestone in a local basin near Tatung-fu, Shan-si (quoted by Willis and Blackwelder, loc. cit., vol. 2, p. 90); also, see A. W. Grabau: "The Sinian System." Bull. Geol. Soc. of China, vol. 1, 1922, pp. 44-88.

PU-HSIEN FORMATION

Name and age.—In the field the term Fen-ho was used for the formation here under consideration. The name was also used by Fuller in a talk on China[32] and has been quoted by T. O. Chu[33] in connection with age correlations. In view of the fact that Willis and Blackwelder[34] used the term Fen-ho (Fön-ho) as a Recent stage name, stating, "The fourth and present physiographic stage we named for North China the Fön-ho, from the river of that name," the use of some other name for the sedimentary formation under discussion seems advisable.

FIGURE 6.—*Shaly Phase of the Pu-hsien Formation between Pu-hsien and Ta-ning, Shan-si*

Showing characteristic disturbance in vicinity of a fault (photograph by Fuller).

The name Pu-hsien is here proposed for the series of sandstones and red shales, 1,000 to 2,000 feet or more in thickness, which overlies the Shan-si coal-bearing formation and underlies the hard, platy sandstones of the Shen-si formation. The name is taken from the city of Pu-hsien, about midway between the Hwang-ho and Fen-ho (approximate latitude, 36° 15′ north), near which the red series reaches its greatest and most

[32] Explorations in China. Bull. Am. Assoc. Petrol. Geols., vol. 3, 1919, p. 101.
[33] Am. Assoc. Petrol. Geols., vol. 9, 1925, pp. 1296-7.
[34] Researches in China, vol. 2, p. 99.

typical development (figure 6). It is the equivalent of the deposits included under the name "Red Beds" on the general map of a part of Shan-si by Willis and Blackwelder [34] and assigned by them to the Permo-Mesozoic. The China Geological Survey regards it as "Triassic, lower part probably Permian,"[35] on the basis of fossil-plant collections made by C. C. Wang in the overlying Shen-si beds.

Character and thickness.—The red color of its shales is the distinctive lithological feature of the Pu-hsien formation. Except near the top, where there may be a few thin streaks of red shale, the Shan-si formation is non-red throughout. The same may be said of the Shen-si formation, except, perhaps, its base. Between the lowermost and uppermost red shale there is usually, in Shan-si, a thickness of at least 2,000 feet. Severe folding and faulting (figure 6) render exact measurements difficult to make, and the maximum thickness may reach 3,000 feet or more. In central Shen-si, where the red color disappears, the thickness is uncertain.

Although the red color is conspicuous throughout the formation and individual red shale beds may reach thicknesses of several hundred feet, the red strata are, as a rule, only a few feet thick. They give rise, however, to red stains which coat the exposed faces of other beds and cause the red material to appear to be present in much greater amounts than is actually the case. They probably seldom constitute more than a quarter or third of the formation, the predominating material being yellowish, buff, or pinkish sandstones, often massive and occurring in beds from 30 to 50 feet in thickness. Gray sandstone of the Shen-si type occurs over considerable areas, while dark or black shales are found locally near the base of the formation.

Stratigraphic relations.—The Pu-hsien, so far as seen, overlies the Shan-si coal measures without unconformity. In fact, there is a transitional zone in which the red shales first appear as thin, widely separated layers near the base, becoming thicker and more numerous above until they are the most conspicuous feature of the formation.

In places the Pu-hsien formation rests directly against the Ki-chou limestone. Sometimes this is the result of faulting, but in certain localities the red beds probably overlapped the Shan-si along masses of Ki-chou limestone which remained above water during Shan-si and even Pu-hsien deposition.

Its upper contact is likewise apparently conformable with and transi-

[34] Loc. cit., plate 1.
[35] T. O. Chu: Loc. cit.

tional into the Shen-si formation. It is believed that in western Shen-si there is also, to some extent, a lateral gradation, accompanied by loss of color, into beds resembling both those of the Shan-si and Shen-si formations.

Description of outcrops.—The red color of the transitional zone or base of the Pu-hsien formation was first seen in pinkish cliffs on the Shen-si side of the Hwang-ho opposite Ho-che, near the point where the Great Wall leaves the river on the west, at the western end of Route 1 (figure 2). From this point to beyond Pau-te-chou, 25 miles to the south, the Pu-hsien-Shan-si contact follows the general course of the river, the greater part of the formation lying west of the stream, where it forms a belt 10 to 12 miles wide, only a few red shales being found on the Shan-si side. The first 5 miles from the eastern margin is marked by strong folding and faulting, with dips of from 5 to 45 degrees; beyond, the beds flatten, with westerly dips of 1 to 3 degrees.

On Route 3, at Ching-lo-hsien, about 45 miles west of the valley north of Tai-yuan-fu, Estabrook reported a basin of red shales and associated sandstones having a width of nearly 10 miles (figure 21). The beds conformably overlie the Shan-si on the east, but the area between the Pu-hsien and the Ki-chou on the west is hidden by loess. The formation also occurs on the same route, in a belt 5 or 6 miles in width, at Sing-hsien, south of Pau-te-chou.

The draftsman's plotting on Route 4 shows no Pu-hsien outcrops, but it is known to be inaccurate, and there is a possibility that the formation may occur in a basin, 15 to 20 miles in breadth, lying between Archean uplifts, with some intervening limestone on the east, in the vicinity of Lin-hsien, 35 miles southeast of Chia-chou, on the Hwang-ho, and again on the westerly side of the westernmost Archean uplift, 15 miles southeast of the same city (figure 22). Thick loess obscures the geology at the critical points.

Fuller found red Pu-hsien beds outcropping for 12 miles along a small valley running about north 30 degrees west and connecting Routes 5 and 6 and crossed by the latter at a point 3 to 4 miles southwest of Yung-ning-chou (figure 23). The direction of the valley is approximately that of the strike of the beds. The red beds appear to rest on the Ki-chou limestone, probably along a fault-contact, for several miles, but are separated from the limestone at the north and south ends, near points of junction with the routes mentioned, by limited thicknesses of Shan-si measures. Barnett also found red Pu-hsien beds above the Shan-si formation on the west side of the most westerly Archean and Ki-chou

uplift, 10 miles east of the Hwang-ho, on Route 5, with continuous outcrops to the river. The general inclination of these beds is westward, but is interrupted by sharp folds and many small faults. West of the Hwang-ho the dips subside to a few degrees, and the beds disappear under the Shen-si formation within a distance of a mile or two.

On Route 6 Fuller found red Pu-hsien beds at the edge of the Fen-ho plains and, again, some 2 miles from the most westerly outcrop of Ki-chou limestone, at a point about 35 miles east of the Hwang-ho (figure 24). The internal between the limestone and red beds was covered by thick loess. The red belt has a width of between 15 and 20 miles and is characterized by a prevailingly westward inclination, broken by faults and by many strong folds (figure 6) with dips of 20 to 30 degrees, sometimes increasing to 80 degrees on the east, but subsiding to 30 degrees on the west, where the Pu-hsien dips beneath the Shen-si formation. Certain of the gray shales and sandstones occurring with the red beds may possibly belong to the underlying Shan-si formation, brought up by anticlines.

Clapp, on Route 7, also observed the Pu-hsien red beds at the edge of the Fen-ho plains. They are again found a mile or two west of the westernmost outcrop of the Ki-chou limestone flanking the granite uplift 35 miles east of the Hwang-ho. Thick loess covered the area intervening between the Pu-hsien and the Ki-chou and also the contact with the overlying Shen-si formation, but the Pu-hsien belt appears to have a width of 15 to 20 miles (figure 25). The structure is similar to that on Route 6.

On Route 8, traversed by Fuller, the Pu-hsien red beds cap the mountain summits 25 miles west of Hung-tung above a syncline of Shan-si beds (figure 26), while the westerly Pu-hsien belt widens to 30 miles. On the east the formation rests on the Shan-si coal measures, dipping westward to an angle of 45 degrees at the contact, which is about 55 miles east of the Hwang-ho and 10 miles southeast of the city of Pu-hsien, from which the name of the formation was derived. While warping and minor faulting is conspicuous, the folds are less sharp than to the north, and the dips may often be aptly described as wavy. The lower portion of the formation for a distance of 2 to 3 miles from its basal contact is marked by a large proportion of red shale, with a few gray shales at the transition into the underlying Shan-si formation, the total thickness of the red phase being several hundred feet. To the west the shales are followed by a belt of similar width characterized by massive gray sandstones dipping gently westward beneath a second red shale zone reaching

3 miles to Pu-hsien, thence northwestward for an additional 7 miles. Throughout the easterly two-thirds of the red belt under discussion the beds are gently folded with dips of 2 or 3 degrees, but in the western third the beds locally dip toward the east at angles of 30 degrees to 35 degrees, suggesting that the gray sandstones exposed immediately to the west may mark the reappearance of those seen east of Pu-hsien. The succeeding 5 miles are characterized by alternating belts of red and gray beds, with sharp anticlines, faults, and one or more crushed zones, the inclination of the formation as a whole being westward. Beyond, the beds are predominantly red to Ta-ning, a distance of 6 miles. The field-

FIGURE 7.—*Massive Pu-hsien Beds*

These beds give rise to Falls of the Hwang-ho in latitude 35° 50′ north (photograph by Barnett).

notes, in describing this part of the formation, state that the rocks consist of massive gray or pinkish feldspathic sandstones, often 30 to 40 feet or more thick, alternating with bright red zones of 50 feet or so in thickness, consisting of dark red or purplish shales from 2 to 10 feet in thickness separated by red or gray sandstones from 1 to 3 feet thick. The proportion of standstone increases and that of the red shale decreases toward the west. Dips decline from 10 to 3 degrees or less. The change to the Shen-si formation, which in the uplands occurs just west of Ta-ning and some 10 miles east of the Hwang-ho, is marked by a transition zone several miles in width and several hundred feet in thickness, in which the red shales gradually disappear and the pinkish sandstones are

replaced by massive gray sandstones. Although the Pu-hsien dips under the Shen-si in the uplands, the pinkish transition zone reappears in the bottom of the deep canyon of the Hwang-ho, but is not exposed much west of the latter in Shen-si. The beds are described as dark shales, some with a purplish tinge, alternating with pink or mottled feldspathic sandstone.

On Route 9, as noted by Clapp, the Pu-hsien was found resting in a sharp fold against a fault separating it from the Ki-chou limestone of the great 'O-shan horst, but the dips almost immediately flatten and continue without important reversals to the Hwang-ho, 20 miles to the west, where the inclination is from 1 to 3 degrees to the northwest (figure 27).

At the Great Falls of the Hwang-ho, known as Lung-wan-chan, in latitude 35° 50′, the grayish sandstones of the upper Pu-hsien form the resistant ledges over which the water plunges (figure 7), as well as the lower part of the canyon walls. The river continues southward diagonally across the strike of the Pu-hsien formation for 30 miles, cutting the formation from top to bottom. The dips are usually 1 degree or less to the northwest, but with an occasional local roll showing inclinations up to 5 degrees or more.

On the Shen-si side of the Hwang-ho, about midway between Routes 9 and 10, Fuller found the upper phase of the Pu-hsien formation, here consisting mainly of yellowish or pinkish sandstones with enough red shale to stain the entire outcrop, reaching westward beneath the Shen-si formation up the bottom of a tributary stream for a distance of from 15 to 20 miles, but the Shen-si beds approach close to the river in the uplands.

No Pu-hsien beds were noted by Fuller on Route 10, but they come in above the Shan-si formation at river level a few miles to the north on both sides of the Hwang-ho. Southwest of the river the rocks are everywhere hidden beneath loess of unusual thickness for a distance of many miles. The Pu-hsien is, however, known to occur in an upland valley about 1,000 feet above the river named and 4 miles north of Ho-yang. The deep valley of the Lo-ho did not cut into the rock where crossed by the field parties. A few red shales were seen in the loess uplands 15 to 20 miles southeast of I-chun. At Tung-kwan-hsien red shales are exposed for 2 miles above the Shan-si coal measures in a small basin, while 2 miles to the north a slight thickness, lying below Shen-si beds, is tilted upward against a fault (figure 5). The outcrops are here near the northern limits of the marginal zone of marked folding and faulting

along the south side of the North Shen-si Basin. The Pu-hsien formation was not recognized farther west, nor was anything that could be correlated with it observed in the western part of the basin in Kan-su. It is a question whether it thins out and disappears to the west, is overlapped and covered by later Jurassic beds, or loses its red character and becomes indistinguishable from the underlying Shan-si and overlying Shen-si formation. It is possible that all three are factors in its westerly disappearance.

JURASSIC

GENERAL CONDITIONS

The Jurassic witnessed intense orogenic disturbances in the areas surrounding the North Shen-si Basin. In west Shan-si, where all beds up to the Pu-hsien (Permo-Triassic) are involved, the active compression giving rise to the great folds of the mountainous region between the Fen-ho and the Hwang-ho probably began in early Jurassic and continued into middle or late Jurassic times. Both intrusions and extrusions occurred on a large scale in other parts of northeastern China, especially in Chih-li, but within the North Shen-si Basin or near its borders only a few indications of such activity were noted.

On the south side of the basin the orogenic and igneous activities were of similar character. The strong folds of the Tsin-ling and Ta-hua ranges, with the associated intrusives, belong to this period. Within the basin, beds as late as lower Shen-si were involved. No details of conditions on the west and north sides of the basin are available, but the histories are probably not greatly different from those on the east and south.

As the surrounding areas were uplifted, the embayment constituting the North Shen-si Basin was correspondingly depressed and some 12,000 feet of Jurassic strata deposited within it. As indicated above, the area of disturbance extended outward and involved the earlier beds before the deposition of the later Jurassic sediments, the marginal basin beds being distinctly folded and faulted locally before accumulation of the latest Jurassic formations. The tilting of the basin beds appears to have been subsequent to the main period of folding. The fact that the Hwan-hsien phase of the Hwan-ho formation (latest Jurassic) is nearly horizontal, while all earlier beds partake of the inclination, suggests that the tilting occurred just before the deposition of the phase named.

The land areas during the Jurassic were broad and at times considerably elevated. The immense quantities of quartz present in all the

Jurassic formations, as well as the important amounts of feldspar and mica in the lower beds, points to the removal of the Ki-chou limestone and the exposure of Archean or Algonkian rocks over large areas. These, however, were greatly reduced in altitude by the end of the Mesozoic.

The absence of marine fossils in the greater part of the Jurassic beds points to a general lack of connection with the open sea, but it is possible that the limestones associated with the coals of the Shen-si formation may be found to have a marine fauna, in which case a temporary connection with the ocean would be indicated.

The Jurassic presumably saw many changes in climatic and depositional conditions. With the inauguration of early Jurassic (Shen-si) deposition the conditions became less favorable to the transportation of fine silts, and the accumulation of argillaceous clays almost ceased, gray, often cross-bedded quartzose sands and sandy clays taking their place. At the same time the climatic conditions seem to have become more humid, with sufficient organic matter at hand during the breaking down of the rocks and during the deposition of the resulting sediments to deoxidize the iron and remove all traces of red color which characterized parts of the Permo-Triassic sediments. The early deposition, as indicated by the general prevalence of cross-bedding, took place in shallow water, but was not, as a rule, of subaerial type.

At a later period there was a partial return to littoral conditions, with lagoons, in which the coals, shales, and limestones of the coal-bearing (Yen-an-fu) phase of the Shen-si formation were laid down. The massive sandstones associated with the coal series as well as those of the Tien-tou phase of the same formation are indicative of rapid deposition not far removed from the coastline of the time. Certain of the sandstones may even represent dune accumulations. The reappearance of red colors at the top of the Shen-si, although local and inconspicuous, points to a change to a more arid climate.

The red shales and limestones of the An-ting formation grade laterally into the I-chun conglomerate toward the south. They may mark the establishment of a decidedly more arid climate, the approach of which had been foretold by the local reappearance of pink colors in the upper Shen-si, but color alone is not a positive guide to climatic changes.

The Lo-ho sandstones appear to mark an uplifting of the region to a point above sealevel, since the character of the false-bedding seems to point to wind rather than water accumulation (figure 15). After a certain period, subsidence again carried the beds temporarily under water, but the accumulation continued to be mainly subaerial until 2,000 feet or more of sands were laid down.

The transition from the Lo-ho to the Hwa-chi was accomplished by a subsidence which allowed the waters of the basin to cover the Lo-ho beds and permitted the accumulation of water-bedded sediments. There were, however, temporary returns to land conditions with more wind deposition from time to time until a total of 1,000 feet of sandy beds had accumulated.

Following the deposition of the last of the land deposits of the Hwa-chi, the waters once more took possession of the basin and at least 3,000 feet of shales and sandstones, represented by the Hwan-ho formation, were laid down on the subsiding bottom. The amount of organic matter, probably dependent on climatic changes affecting humidity, varied from time to time, some of the beds, notably the gray and green shales, showing its presence in the original products of weathering or in the silts themselves in quantities sufficient to completely reduce the iron, while the red shales point to the general absence of such matter. Of the three phases, the lower, or Tan-pa-li appears to show the prevalence of arid conditions, the second, or King-yang, points to probable alternations of arid and humid conditions of weathering if not of climate, and the third, or Hwan-hsien, phase to the prevalence of humid conditions. The Tien-chi gypsum is significant of aridity.

Unconformities of the erosion type are to be found, on search, in practically any formation of the Jurassic, but they appear in general to represent contemporaneous erosion and deposition and to be of only local interest. The disconformities indicated by the overlaps of certain of the beds are mentioned in the discussion of the formations.

SHEN-SI FORMATION

Name.—In a chapter entitled "Geological notes," in the report of the Clark expedition of 1908-1909, the zoologist of the party, Mr. Sowerby, gives an intelligent summary of the rocks met with in crossing western Shan-si, Shen-si, and eastern Kan-su. In this he says:[36] "For want of any other name, I call the sedimentary beds of Shen-si the Shen-si formation." The name is a good one, for the beds to which he refers cover almost the entire northern portion of the province, extending from the Hwang-ho nearly to the Kan-su line, and from the Ordos to the southern edge of the North Shen-si Basin. Since no upper limit was given and it is stated that "the exact relationship between this and the Shan-si formation, I can not define," it falls to the writers in accepting the term to fix its limits. As here used, the Shen-si formation may be defined as

[36] Robert S. Clark and Arthur C. Sowerby: Through Shên-kan, London, 1912, p. 116.

the great series of shaly or platy sandstones, with thin local limestones, shales, coals, and an occasional massive sandstone, which overlies the reddish Pu-hsien formation and underlies the An-ting limestone and I-chun conglomerate, or, when these are absent, the thick false-bedded Lo-ho sandstone.

C. C. Wang used the term "Lower Jurassic (Liassic) Coal Series"[37] for what is here known as the Shen-si formation, but the usage is objectionable from the fact that the coal-bearing portion (Yen-an-fu phase) constitutes only about one-sixth of the formation.

Age.—Some years after the completion of the work on which the present paper is based, the China Geological Survey sent a party across northern Shen-si. Fossil plants of Lower Jurassic age were collected, probably from the Yen-an-fu coal-bearing phase, while fish remains of Upper Jurassic age were found in the overlying An-ting limestone.[38]

Thickness.—The Shen-si is predominantly a sandstone formation having an average dip of about half a degree to the west or northwest. It is possible, however, that a part of the inclination is that of original deposition rather than the sole result of tilting, and that, although none was actually observed, there may also be a westward thinning of the beds partly counterbalancing the apparent dip, so that the actual thicknesses and depths of the strata at a given point may be less than computed. On the other hand, dips of several degrees often occur locally, and it is more likely that the average inclination is greater rather than less than estimated. The distance from the outcropping base of the formation in Shan-si to its top, 40 miles west of Yen-an-fu, is 100 miles, corresponding, on the basis of a dip of 50 feet per mile, determined by stadia, alidade, and level measurements, to a thickness of 5,000 feet. Allowing for the increase of 2,000 feet in elevation toward the west, the apparent thickness would be 7,000 feet. The depth of the Pu-hsien beds in the deep well at Yen-chang, 30 miles west of their outcrop, showed the correctness of the estimates in the east, or most complicated region. The average thickness of the Shen-si formation for the basin as a whole is probably not far from 6,000 feet.[39]

Yen-chang phase.—Although predominantly sandstone throughout (figure 8), the Shen-si formation varies considerably in character in its

[37] On the stratigraphy of North Shen-si. Bull. Geol. Society of China, vol. 4, pt. 1, 1925, p. 59.

[38] C. C. Wang: Loc. cit., pp. 58 and 59.

[39] C. C. Wang, in his paper previously quoted, gives the thickness of the Shen-si series as 500 meters, an amount which is hardly more than may be seen in single sections in the Hwang-ho Canyon.

various portions. Above 500 feet of basal transitional beds in which pinkish coloration similar to that of the underlying Pu-hsien beds is sometimes, although not usually observed, there is 3,500 feet of hard, dense, gray sandstone, usually in thin strata which are often cross-bedded. The exposures sometimes have the appearance of shale, but examination usually shows them to be fine-grained, laminated sandstone, often with mica along the parting planes (figure 9). Very little argillaceous shale occurs. The exposures show only slight variation in general character

FIGURE 8.—*Gorge of the Hwang-ho east of Yen-chang, Shen-si*

Showing essentially horizontal Shen-si sandstones of the Yen-chang phase in cliffs about 700 feet in height, the tops of which approximately mark the level of the pre-loess valley of the river. The eroded overlying loess forms the irregular skyline (photograph by Clapp).

from point to point, and there is practically an entire absence of distinctive beds that could be used for determining structure. One or two shaly beds persisted for a mile or two, but nothing was noted by any of the geologists which could be followed for any considerable distance. Dip determinations were based on local laminæ, which could seldom be recognized for distances of more than 100 to 200 feet. The general aspect of parts of the formation suggests the Pocono of the United States, but the grain is finer, the cross-bedding less persistent, and the greenish color not so conspicuous.

The lower sandstones have been termed the Yen-chang phase from the

town of Yen-chang, Shen-si, at which point oil wells have been drilled in the sandstones under discussion. They have not been made a distinct formation because of the absence of easily recognizable physical characteristics which might be used as boundary markers.

Yen-an-fu phase.—The Yen-an-fu phase, having a thickness of about 1,000 feet, may be taken as reaching from the base of the conspicuously massive sandstone in which the rock temples have been excavated at Kan-ko-yi, 20 miles east of Yen-an-fu, to the top of the similar heavy sandstone, also carrying temples, in the valley of the Yen-shui at Yen-

FIGURE 9.—*Irregularly bedded platy Sandstone of the Yen-chang Phase of the Shen-si Formation*

In the vicinity of Yen-chang, Shen-si, showing type of notching by recently rejuvinated streams (photograph by Fuller).

an-fu (figure 10). The phase may be said to be characterized by massive sandstone lenses at top and bottom, with shales, thin limestones, and two or more very persistent horizons of workable coals which have been traced from the Ordos southward to Tien-tou, west of Chung-pu. The individual sandstone lenses can not be correlated for any considerable distance.

Tien-tou phase.—The Tien-tou phase includes the 800 feet or more of massive gray to reddish sandstones, with gray to greenish shales, constituting the top of the Shen-si formation and overlying the pyrite bed

200 feet above the coals near Tien-tou, west of Chung-pu. One of the characteristics of the type locality is the presence of a pink or red coloration, indicating the beginning of the change to more arid climatic conditions following the long period of normal Shen-si deposition.

The base of the Tien-tou phase appears to be not far from the horizon of the top of the Yen-an-fu phase at Yen-an-fu, and would therefore correspond to the 1,500 feet of sandy shales and sandstones west of Yen-an-fu. The southward decrease in thickness of the exposed beds above the Yen-an-fu phase is partly due to overlap by the An-ting and I-chung

FIGURE 10.—*Massive Sandstone constituting top Member of the Yen-an-fu Phase of the Shen-si Formation near Yen-an-fu, Shen-si*

Showing faint local arch and abandoned rock temples (photograph by Fuller).

formations, but if the red color of the upper part of the Tien-tou phase is indicative of transitional conditions, and therefore marks the close of Shen-si deposition, there must also be a real thinning to the south.

Stratigraphic relations.—The Shen-si formation, so far as seen, lies conformably upon the Pu-hsien formation, with a certain thickness of what may be termed transitional beds. The cessation of the red color characteristic of the Pu-hsien, which was the basis of field mapping, probably does not occur at the same horizon at all places. Nevertheless, the range is not great and its effect upon the boundary is hardly noticeable

on maps of moderate scale. The pink color locally noted in the lower portion of the Shen-si formation is largely due to feldspathic grains in the sandstone, but dark shales with a purplish tinge are also known near the base.

So far as dips are concerned, the top of the Shen-si formation is generally conformable with the overlying beds. Nevertheless, if the coals outcropping from the Great Wall to Tien-tou belong to the same general horizon, it is evident that there must be an important unconformity at the top of the formation. The overlapping An-ting-I-chun horizon approaches constantly nearer that of the coals. In North Shen-si the two are separated by a distance of over 20 miles; at Yen-an-fu the interval has decreased to about 10 miles, while at Tien-tou the coals are almost under the I-chun horizon. The thickness of the intervening beds decreases, at the same time, from more than 1,500 feet north of Yen-an-fu to less than 1,000 feet near Tien-tou. In the region west of I-chun the Shen-si beds appear to have been warped or gently folded before the deposition of the I-chun conglomerate. The marked change in conditions, as shown by the change from gray sandstone to bright red shale and limestone of the An-ting formation in the north and to the red conglomerate and shales in the south, afford additional evidence of disconformity, if not of unconformity.

Descriptions of outcrops.—In describing the exposures of the Shen-si formation, the start is made at the Shen-si-Pu-hsien contact, in the extreme northeast corner of Shen-si, and the formation followed westward across its outcrop. The description of the exposures on north-south traverses intervening between the preceding and the next east-west traverse on the south then follow. The distances are airline measurements taken from the maps, as distances by trails, because of the constant changes of the latter are of little value.

The description of the larger portion of the northeastern exposures are based on the work of Clapp, Estabrook, and Barnett; those of northwestern Shen-si, Kan-su, and west-central Shen-si on traverses by Fuller; those of the Tien-tou-Chung-pu region on the investigations of Clapp and Estabrook, while those on the south side of the basin are based on the routes of Fuller and Estabrook. All geologists had a part in the exploration of the eastern and central portions of the basin, but because of the complicated network of routes it is impracticable to give specific credit to individuals.

Pao-te-chou to Yu-lin-fu.—The most northerly exposures of the Shen-si formation noted were along the south side of the Great Wall, between

the Hwang-ho opposite Pau-te-chou and Yu-lin-fu, nearly 100 miles to the southwest. The Yen-chang phase comes in above the Pu-hsien red beds about 10 miles west of the river. The general dip is westward at the rate of 1 degree or less, with little warping, for nearly 65 miles. Agglomerate and tuff were noted 25 miles northeast of Yu-lin-fu.[40] Thick loess and overlying desert sands cover the outcrops for the remaining distance, but the Yen-an-fu phase probably replaces the Yen-chang about 15 miles northeast of Yu-lin-fu.

Chia-chou to Yu-lin-fu.—The eastern margin of the Shen-si formation crosses the Hwang-ho from Shen-si into Shan-si 15 to 20 miles southwest of Pau-te-chou and extends southward, gradually diverging from the river, which occupies a canyon in rocks of the Yen-chang phase, to a point at least 15 miles east of Chia-chou. Loess obscures the geology over much of the 50 miles between this city and Yu-lin-fu, but beds of the hard, sandy Yen-chang phase appear to continue to within 12 or 15 miles of the latter city, beyond which they are replaced by the coal-bearing Yen-an-fu phase.

A considerable number of pits and small coal openings are reported 4 to 5 miles east of Yu-lin-fu, while a thin coal was seen in a ravine 5 miles farther east. The beds were said to be ordinarily from 2 to 3 feet in thickness, but in places they thicken to 4 or 5 feet, while elsewhere they thin out to a few inches. Local pockets exceeding the normal maximum probably occur. The coals are described as of a dirty bituminous type, the amount of slate usually being considerable in the thicker beds. The coals give much smoke and the percentage of ash is usually high.

Yu-lin-fu to Sui-te-chou.—Southeastward from Yu-lin-fu the Yen-an-fu coal-bearing phase of the Shen-si formation outcrops in the valley of the Yu-lin-ho to its junction with the Wu-ling-ho at a distance of about 25 miles; thence downstream along the latter for a farther distance of 15 to 20 miles. For the remaining 30 miles to Sui-te-chou the beds along the Wu-ling-ho are mainly gray sandstones of the Yen-chang phase. The prevailing dips are less than 1 degree to the west. The beds of the Yen-an-fu phase are practically without warping, but a few slight disturbances were noted in the Yen-chang phase. These include a fault, showing a 50-foot downthrow to the north, at a point 5 miles north of

[40] C. C. Wang, in his paper, "On the stratigraphy of North Shen-si," Bull. Geol. Society of China, vol. 4, pt. 1, 1925, pp. 60-61, also reports a volcanic agglomerate and a mass of lava mingled with fragments of sandstone at Wu-su-ku-chang (location not identified). It is said to be near the coal horizon and to be taken by the natives as an indication of workable beds. A baked contact was observed at Shan-shen-miao-kou northeast of Yung-hsing-pu.

Mi-chih-hsien, 35 miles southeast of Yu-lin-fu, and weak anticlinal rolls with dips not exceeding 1½ to 2 degrees at points respectively a mile south of Mi-chih-hsien and 4 miles north of Sui-te-chou.

A coal which burns well but gives a dense smoke is mined north and south of Kuei-te-pu, 10 miles south of Yu-lin-fu. It is probably of the same general horizon as that worked 4 to 5 miles east of the latter city, if not the same bed. The so-called mines are usually shallow pits and tunnels of no great length, but shafts have been sunk to the coal in places. All labor is done by hand, even the water, when it can not be removed

FIGURE 11.—*Wu-ling-ho disappearing through Sandstone in Yen-an-fu Phase of Shen-si Formation*

Near Hsiang-shui-pu, 15 to 20 miles southwest of Yu-lin-fu, Shen-si (photograph by Estabrook).

by natural drainage, being carried out in buckets. The amounts mined are relatively small and are transported to the nearer cities and villages by mules.

Near the small town of Yo-ho-mao, 20 miles southeast of Kuei-te-pu, a mine is reported on a coal of approximately the horizon of that found 10 miles east of Yu-lin-fu. Saline waters are evaporated for salt in the vicinity. Pebbles in the stream beds apparently indicate the presence of thin limestones a few miles farther southeast.

Yu-lin-fu to Chun-ching-pu.—This route follows the preceding to Kuei-te-pu, then strikes southwestward across a region of sandy hills south of the Great Wall, through Huai-yuan to Chun-ching-pu. Flat-

lying or gently westerly dipping sandstones and shaly sandstones, with a little shale, are exposed at intervals to a point 12 miles southwest of Huai-yuan, 35 to 40 miles southwest of Yu-lin-fu, when the Shen-si disappears. The sandstones of the Yen-an-fu phase are probably represented in the vicinity of Yu-lin-fu and also near Hsiang-shui-pu, where the Wu-ling-ho plunges through a massive sandstone forming a striking natural bridge (figures 11 and 12). The greater part of the beds crossed belong to the Tien-tou phase or horizon. The An-ting limestone, although not noted on the route itself, probably extends northward to beyond the Great Wall in the region of Huai-yuan.

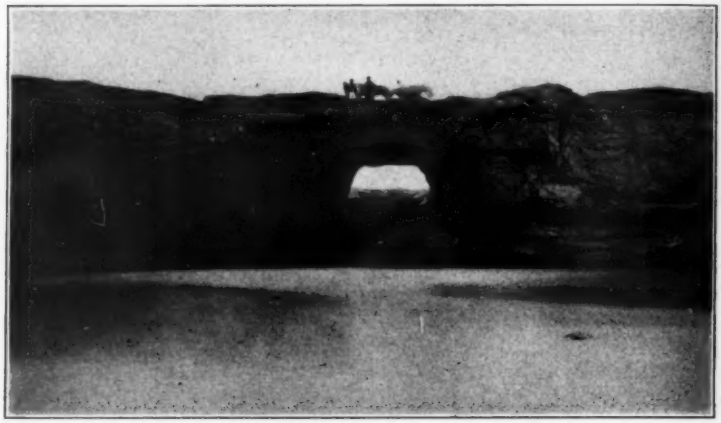


FIGURE 12.—*Another View of Wu-ling-ho*

Looking back through 300-foot tunnel under the natural bridge (photograph by Estabrook).

Hwang-ho to Sui-te-chou.—The base of the Shen-si formation is seen above the Pu-hsien beds about 3 miles west of the Hwang-ho, and the Yen-chang phase continues to occur in ravines cut through the loess at short intervals to Sui-te-chou, 30 miles west of the river. Five faults were noted, and there are doubtless others. The throws are small, however, and the beds are but little disturbed by folding, the dips seldom being more than 1 degree or 2 degrees.

Sui-te-chou to Yen-chang.—From Sui-te-chou southward 65 miles. to Yen-chang, the usual hard, dense, platy, gray sandstones of the Yen-chang phase prevail. The normal dips are westerly or northwesterly at a rate of half a degree or less, but with local rolls with inclinations up to 2 or 3 degrees. No large structures were recognized nor important

faults noted. Small oil seepages, often mere stains, occur at several points a short distance north of Yen-chang. Other seepages occur within a few miles to the east, south, and west of the city, while two shallow wells sunk by the Chinese in 1907-1911 still yielded a few barrels of oil per month in 1914.[41]

Sui-te-chou to Wang-yao-pu.—The trails lead southwestward, mainly along stream valleys, with frequent showings of sandstones of the Yen-chang phase of the Shen-si formation for 15 miles; thence westerly through loess hills for a similar distance. The change to the Yen-an-fu phase probably occurs beneath the loess about 20 miles northeast of Wang-yao-pu. A limekiln utilizing a thin local layer of limestone was found 15 miles northeast of the latter city, while outcrops and other kilns were seen 4 miles north of town. Coal mines were noted 10 miles north, 6 miles east, and 4 miles west of town. The coals are all thin, bituminous in character, and very smoky. A "lignite" was reported from An-ting, but may come from the bed 4 miles west of Wang-yao-pu (5 miles east of An-ting). Other coals were seen 8 miles southeast and 15 miles south of Wang-yao-pu. Three beds are probably represented. Several fireclays were noted. An oil seepage was found 15 miles southwest of the city.

Local domes and anticlines of small magnitude were recorded at several points, especially in the region southeast of Wang-yao-pu, and a number of faults were seen. The dips near the latter are from 15 degrees to vertical, but only small thicknesses of beds are affected. The normal dip is westward at an average angle of less than one degree, although local dips of from 2 to 3 degrees were noted.

Wang-yao-pu to Yen-an-fu.—The trail, although somewhat devious in detail, leads nearly due south to the Yen-shui; thence 10 miles southwestward to Yen-an-fu. Coal and fireclay were seen 2 miles southwest of Wang-yao-pu. Other coal outcrops were noted 15, 17, 19, and 20 miles south, all apparently the same bed or of the same general horizon. An oil seepage was reported about 25 miles south of the same city, or 5 miles north of the Yen-shui. A coal mine and outcrops, probably of the same horizon as those along the trail to the north, were found a mile or two north of the Yen-shui, 10 miles northeast of Yen-an-fu. The route follows the general strike of the Yen-an-fu phase of the Shen-si formation for its entire length.

[41] For details of oil seepages and prospects see writers' paper on "Oil prospects in northeastern China," quoted in introduction.

Hwang-ho to Yen-chang.—The eastern margin of the Shen-si outcrop is from 5 to 20 miles east of the Hwang-ho, the exact distance depending on the elevation of the uplands of western Shan-si. The river at the sharp reversed U-bend northeast of Yen-chang flows some hundreds of feet above the base of the Shen-si formation, while higher sandstones of the Yen-chang phase are exposed in the canyon walls to considerable heights (figure 9). Similar beds are also found along streams which have cut through the loess to Yen-chang, 20 miles west and 8 miles south of the bend. The sandstones are dense, hard, platy, and often cross-bedded, locally interrupted by small structures (figure 13), with a general

FIGURE 13.—*Characteristic local Structure in the Yen-chang Phase of the Shen-si Formation*

The locality is 8 miles east of Yen-chang, Shen-si. Few structures extend for more than a few hundred feet, and it is doubtful if they persist to any considerable depth (photograph by Estabrook).

dip, decreasing from 1 to 2 degrees near the rim to one-half to one degree at Yen-chang. The deep American well at the latter city, 40 miles west of the outcrop of the top of the Pu-hsien, is said to have encountered the red beds of the formation named at about 2,500 feet, pointing to a westerly inclination of about 60 feet per mile, without allowing for differences in elevation, which probably do not exceed 200 feet. The average westerly dip is, therefore, but little over half a degree.

At the Hwang-ho, 15 miles southeast of the U-bend, the rocks near river level show reddish shales, apparently transitional between the Pu-hsien and Shen-si formations. Pinkish feldspathic sandstones occur at

least 5 miles west of the river, on a route parallel to that described in the preceding paragraph, and are followed by sandstones of the normal grayish Yen-chang phase, with much sandy shale, beyond which gray sandstones predominate to Yen-chang. Several weak anticlinal rolls, local domes, and small faults occur, but no strong structures were observed.

Yen-chang to Yen-an-fu.—This route follows the cart-road along the valley of the Yen-shui. The ordinary platy gray sandstones of the Yen-chang phase prevail to Kan-ko-yi, where the general trend of the valley bends sharply from northwest to west at a point 18 miles northwest of Yen-chang. Just west of Kan-ko-yi is found the unusually massive basal sandstone of the Yen-an-fu phase, in which several small rock temples have been excavated.[42] Above this sandstone, shales and shaly sandstones predominate to Yen-an-fu, with coals, mentioned in the description of the route from Wang-yao-pu to Yen-an-fu, 10 miles northeast of the latter city.

Yen-an-fu and vicinity.—The massive sandstone marking the top of the Yen-an-fu phase occurs in the lower portion of the bluffs at Yen-an-fu, and, as in the lower sandstone at Kan-ko-yi, several temples have been excavated within it on the east side of the Yen-shui and a tributary from the south (figure 10). The "Temple of Ten Thousand Buddhas" has approximately that number of images carved on the walls, in addition to large statues carved from columns left in the middle. Reentrant shelves at the base of the sandstone have been walled up locally to form a type of cliff-dwelling.[43] The sandstone is one of the few beds of the Shen-si formation which could be followed for more than a fraction of a mile. It is found in the valleys of the tributaries of the Yen-shui east of Yen-an-fu and shows at least one distinct structural terrace 3½ miles northeast of the city of Yen-an-fu. It dips westward below the valley of the Yen-shui a little north of town. Several small oil seepages are found in the shaly sandstones and shales above the thick sandstones west of Yen-an-fu.

Northwest of Yen-an-fu.—The Tien-tou phase of the Shen-si formation is exposed for a distance of about 35 miles up the valley of the Yen-shui to the northwest, finally disappearing under the An-ting limestone. The rocks consist of gray shales and sandstones. Dips are normally flat throughout, but are locally as high as 5 degrees near the limestone.

[42] M. L. Fuller: Explorations in China. Bull. Am. Assoc. Petrol. Geols., vol. 3, 1919, p. 108.

[43] M. L. Fuller: Loess and rock dwellings in Shen-si, China. Geog. Review, vol. 14, 1924, p. 225.

West of Yen-an-fu.—Ascending from Yen-an-fu, at an altitude of about 3,100 feet, to the top of the Shen-si formation, at 4,000 feet, in the hills 15 miles to the west, the beds are described as shales, shaly sandstones, and sandstone lenses of the Tien-tou phase. Dips are from 1 to 2 degrees to the west, with a few local rolls. One or more oil seepages occur.

Yen-chang to Falls of Hwang-ho.—The trail followed led south and southeast over high broken loess plateaus with intervening stretches of sharply trenched valleys, in the bottoms of which the hard gray sandstones and sandy shales of the Yen-chang phase were exposed with dips of one degree or less to the west. The transitional contact with the underlying Pu-hsien red beds is in the lower portion of the canyon at the falls, 40 miles southeast of Yen-chang.

Yen-chang to Yi-chuan.—There are several trails, some bearing nearly south and some bending west and later to the southeast. All are characterized by remnants of loess plateaus and by loess hills reaching altitudes of 4,500 feet, or nearly 2,000 feet above Yen-chang. The rocks exposed in the deeper ravines are of the normal hard sandstone and sandy shale of the Yen-chang phase, with inclinations often too low to measure, but reaching an angle of 2 degrees to the west at several points west of Yi-chuan.

Yi-chuan to the Hwang-ho.—The trail passed south and southeast over high hills with relatively little loess and crossed several deep valleys in which the Yen-chang phase is well exposed, with westerly dips increasing from a maximum of 4 degrees at a point 10 miles south to 10 degrees at the Pu-hsien contact, 17 miles southeast of Yi-chuan and 15 miles east of the Hwang-ho.

Yi-chuan to Chung-pu.—Going westward up the valley from Yi-chuan, the gray Yen-chang phase is exposed with westerly dips decreasing from a maximum of 2 degrees near Yi-chuan to one-half to one degree at a point 25 miles west of the city. The trail here turned south over high loess hills with few outcrops for 20 miles, to Chiu-hsien. Ten miles south of the latter the Shen-si is described as "alternate beds of hard sandy shale and soft yellowish green shale, with lenses of massive cross-bedded sandstone." These beds are apparently below the coal zone and probably belong near the horizon of the sandstones in which the temples are excavated at Kan-ko-yi. The beds are increasingly shaly to Chung-pu, 25 miles southwest of Chiu-hsien. No coals were recorded, but an oil seepage was reported to the west of the route.

Yen-an-fu to Fu-chou.—The cart road runs south over loess divides to the Lo-ho at Kan-chuan, 25 miles from Yen-an-fu; thence down the

valley of the river named to Fu-chou, or Fu-hsien, about 40 miles south of Yen-an-fu. The rocks are of the somewhat shaly types characteristic of the Tien-tou phase of the Shen-si formation, but with one conspicuous bed of red shale. The road follows the strike of the formation. Coal is found off the line of traverse 5 miles northeast and again 10 miles northeast of Fu-chou, probably corresponding to the beds northeast of Yen-an-fu and the upper two beds near Wang-yao-pu.

Fu-chou to Chung-pu.—A cart-road runs along the valley of the Lo-ho, and several trails lead across the uplands to Chung-pu, 30 miles south and 7 miles west of Fu-chou. The horizon of the rocks seems to be about that of the beds at Yen-an-fu, but the thick, massive sandstones of the Yen-and-fu phase have disappeared and no coals are noted on the field maps. The general dips become northwesterly rather than westerly in going south, and the beds show evidence of increasing disturbance, with local terraces, low folds, and several faults. The dips are uusually under 1 or 2 degrees, although occasionally as high as 5 degrees.

Chung-pu to Tien-tou.—From Chung-pu to Tien-tou, 11 miles west and 5 miles north, thin-bedded gray to greenish sandstones and shales, probably belonging near the top of the Yen-chang phase of the Shen-si formation, prevail.

The following general section, reaching from the top of the Shen-si formation in the hills west of Tien-tou to the valley level has been compiled:

General Section, Tien-tou District

	Feet
I-chun formation:	
Red shales and conglomerate	(?)
Tien-tou phase of Shen-si formation:	
Massive gray to reddish sandstones, with gray to yellowish-green shales (base probably belongs to the Yen-an-fu phase)	800
Yen-an-fu phase of Shen-si formation:	
Pyrite bed (pyritiferous sandstone and conglomerate)	2
Green, gray, and black shale	200
Coal (1 to 5 feet, near Tien-tou)	3
Shale and sandstone	100
Coal (3 to 5 feet, near Tien-tou)	4
Shales and sandstone to valley floor, at 2,900 feet above tide	50

Plane-table mapping of the pyrite and associated beds showed a dip of 60 to 80 feet per mile to the northwest, broken by structural noses and small domes. Faulting is observed in the vicinity.

The two workable coals are correlated with the coal-bearing zone, reaching from beyond the Great Wall southward, past Wang-yao-pu,

Yen-an-fu, and Fu-chou, finally bending slightly west to Tien-tou. They apparently disappear, with the rest of the upper Shen-si beds, under the I-chun a few miles to the south of the latter city.

Ho-yang to Chung-pu.—The Shen-si formation was first encountered, in the form of green sandstone, at an altitude of about 2,600 feet, in a ravine cutting through the loess at a point 15 or 20 miles northwest of Ho-yang. Twenty-five miles northwest of the city a southward-facing scarp of Shen-si beds shows above the loess slope on the south. On the north the loess plateau stretches away at the altitude of the summit (3,500 feet), but the deeper ravines, including that of the Lo-ho, cut into the gray or greenish sandstones of the Shen-si formation at intervals of 5 or 10 miles to Chung-pu.

Tung-kwan-ting to I-chun.—From Tung-kwan-ting, near the junction of the Wei-ho with the Hwang-ho at the sharp L-bend of the latter, nothing is seen for 50 miles to the northwest except thick loess, rising in slopes and terraces to more than 1,000 feet above the rivers named. Beyond the Ki-chou, Shan-si, and Pu-hsien exposures, 25 to 30 miles southeast of I-chun, Shen-si sandstones of the Yen-chang phase show near the point at which the loess and rock dissection becomes pronounced. The dip is northwestward at angles of 5 to 10 degrees, with several faults, along one of which there are reversed, or easterly, dips of 12 to 30 degrees. Near I-chun the dips are usually 2 to 3 degrees to the northwest.

I-chun to Tung-kwan-hsien.—Immediately south of I-chun the dips are from 2 to 3 degrees to the west, with little faulting. An oil seepage is found 8 miles south of town. Beyond, there is a series of faults in rapid succession, with the lower gray sandstones of the Yen-chang phase tilted at angles of 10 to 30 degrees, and in one instance to 70 degrees, both to the north and south. The faulting is of the block type, but in the absence of key-beds the details are obscure. The contact with the underlying Pu-hsien red beds occurs about 19 miles south of I-chun and one mile north of Tung-kwan-hsien (figure 5). A second oil seepage was noted in a ravine cutting the Shen-si formation 11 miles northwest of the latter city.

Tung-kwan-hsien to San-shui.—Folded and faulted Shen-si sandstones, probably to be referred to the Tien-tou phase, were noted at San-shui, 45 miles west of Tung-kwan-hsien, and presumably occur beneath the loess in the intervening area. The strike of the beds, which was approximately northeast-southwest at Chung-pu, has probably now become, judging from the trend of the Ki-chou limestone on the south, more

nearly east and west. The I-chun and overlying late Jurassic beds, which overlapped the Shen-si to a horizon as low as the coal beds west of I-chun, have now apparently extended over the Shen-si to a still lower horizon, possibly to the base of the formation.

West of San-shui.—The sandstones of the basal portions of the Shen-si formation probably extend some distance southwestward of San-shui, but the absence of recognizable Pu-hsien red beds makes it difficult to separate the gray sandstones of the Shen-si formation from the greenish sandstones of the Shan-si. As elsewhere stated, the coals of this part of Shen-si are believed to belong to the latter formation.

Kan-su and the Ordos.—The Shen-si formation dips westward or northwestward beneath the later Jurassic beds in western Shen-si, and does not appear to be represented in the faulted zone forming the western margin of the North Shen-si Basin in Kan-su, although the underlying Shan-si formation occurs.

The Shen-si formation extends northward from Shen-si into the Ordos with its full thickness, probably reaching nearly to the Hwang-ho in the northern portion, but it does not appear to have been found north of the great bend of the river mentioned, nor along the stream on the west side of the Ordos.

AN-TING FORMATION

Name.—The name An-ting is applied to a limestone and red shale zone, about 200 feet in thickness, which separates the gray sandstones of the Shen-si formation from the thick, massive red Lo-ho sandtsone in North Shen-si. The name is taken from the city of An-ting, 40 miles north of Yen-an-fu, where the formation is exposed 10 miles or less to the west. The outcrop is usually very narrow and among hills where there are no villages of importance; hence the necessity of selecting a name from the area outside the exposures.

Character and thickness.—The formation consists of 200 feet, more or less, of thin gray to pink limestones, seldom exceeding a few feet in thickness, alternating with somewhat thicker beds of bright red shale, with a 25-foot bed of black shale at the base. Both the limestone-shale series and the black shale bed become thinner to the south, having a thickness of 50 feet and 10 feet, respectively, at a point 25 miles west of Fu-chow. West of Chung-pu, 30 miles farther south, nothing was seen of either the limestone or black shale, their place being taken by red shales and conglomerates of the I-chung formation.

Stratigraphic relations.—As explained in the discussion of the Shen-si

formation, the An-ting limestone overlaps, in descending order from the north, some hundreds of feet of the Shen-si sandstones, but there is otherwise no visible unconformity.

No break was actually observed at the contact with the overlying Lo-ho sandstone, but the presence of conglomerate at the base of the latter southwest of Chung-pu suggests that an unconformity may be present.

Age.—Ganoid fishes, identified as upper Jurassic by Smith Woodward, of the British Museum, have been afforded by the uppermost layers of the An-ting limestone.[44]

Description of exposures.—Fuller noted the limestone and red and black shales on the tributaries of the Yen-shui 10 to 15 miles west of Yen-an-fu, at an altitude of 4,500 feet, or 900 feet above the city. Neither limestones nor black shales were reported by Estabrook or Barnett on either of two traverses southward from the Great Wall near Huai-yuen-hsien, nor on any of three traverses between this city and An-ting. C. C. Wang, however, states[45] that it was found "much more north over a wide area in the neighborhood of Hêng-shan city" (Hwai-yuen?).

In the Yen-an-fu region the limestone and shales gradually descend westward, at the rate of 50 to 100 feet per mile, to the Lo-ho, passing beneath the valley floor at a point 30 miles southwest of and 400 feet above Yen-an-fu. The limestones and red shale here have a thickness of 100 feet and the basal black shales a thickness of 25 feet.

The formation was recognized with reduced thickness 25 miles west of Fu-chou, the limestone and red shales now measuring about 25 feet and the black shale 10 feet in thickness. Neither were reported from any point farther south.

I-CHUN FORMATION

Name.—The bright red shales, sandstones, and conglomerates resting on the Shen-si formation and below the massive Lo-ho sandstone, in the region south and southwest of Tien-tou, have been designated the I-chun formation from the city of I-chun, a few miles west of which the beds are well exposed in the hills.

Character and thickness.—Where crossed by Fuller, 20 miles west of Chung-pu, the formation was represented by 500 feet of red shales.

[44] C. C. Wang: On the stratigraphy of North Shen-si. Bull. Geol. Society of China, vol. 4, 1925, p. 63.

[45] Loc. cit., p. 58.

A similar distance southeast of Chung-pu and a few miles west of I-chun, the field maps of the writers' associates record "soft, shaly, red sandstone with red to gray conglomerate near contact with Shen-si series." Elsewhere the exposures are described as a massive red sandstone 200± feet thick, with alternating thick, soft, red shales and sandstones above. The lower massive sandstones appear to belong to the Tien-tou phase of the Shen-si formation, while the upper soft red shales, etcetera, correspond to the I-chun formation, as observed by Fuller. Conglomerates are reported at about the I-chun horizon at several localities and probably belong at the base of the I-chun formation. Although the data now available are somewhat confusing, the presence of a distinct red shale, sandstone, or conglomerate zone above the Shen-si in the I-chun region may probably be regarded as established.

Stratigraphic relations.—In the north the dips agree with those of the underlying and overlying formations, and no unconformities were noted in any of the sections seen. Southwest of I-chun, however, the presence of the basal conglomerate and the overlapping of the Shen-si beds by the I-chun, as well as the gentle warping of the formation, as compared to the more distinctly folded underlying Shen-si beds, point to an unconformity at the base of the formation. The striking difference in character of the succeeding Lo-ho formation appears to indicate a disconformity at the top of the I-chun.

Age.—The horizon of the I-chun formation is essentially that of the An-ting limestone (Upper Jurassic), of which it is to be regarded as the southern equivalent.

Description of exposures.—From the Lo-ho Valley, 28 miles west of Lo-chou, to the Hsien-ho Valley, 18 miles west of Chung-pu and 20 to 25 miles due south of the first locality, there is a marked change in conditions. At the first locality, 50 feet of pink limestone and red shale, with 10 feet of black shale at the base (An-ting), separate the Shen-si and Lo-ho sandstones; at the second, no limestone or black shale was noted, some 500 feet of red shales (I-chun) here occupying the interval between the Shen-si and Lo-ho formations, outcropping along stream beds for 5 miles. Farther south, west of I-chun, at what is believed to be the same horizon, "soft red shales and conglomerates" are reported.

At two points, respectively 15 and 20 miles southwest of I-chun, "thick, coarse conglomerates" were reported by Estabrook just above the folded and faulted Shen-si formation. Coarse conglomerate was also reported by the same geologist in the hills about Pin-chou-hsien, 50 miles southwest of the preceding. At the first locality the conglomerates, which are

little disturbed, appeared to pass under the Lo-ho formation. No details of the second occurrence are available and there is a possibility that at least a portion may belong to the Lung-chou formation of the Cretaceous. Fuller saw nothing of the I-chun north of Lung-chou.

LO-HO FORMATION

Name.—The name Lo-ho is here given to the thick, massive, but false-bedded, reddish sandstones outcropping in big vertical cliffs for 20 to 25

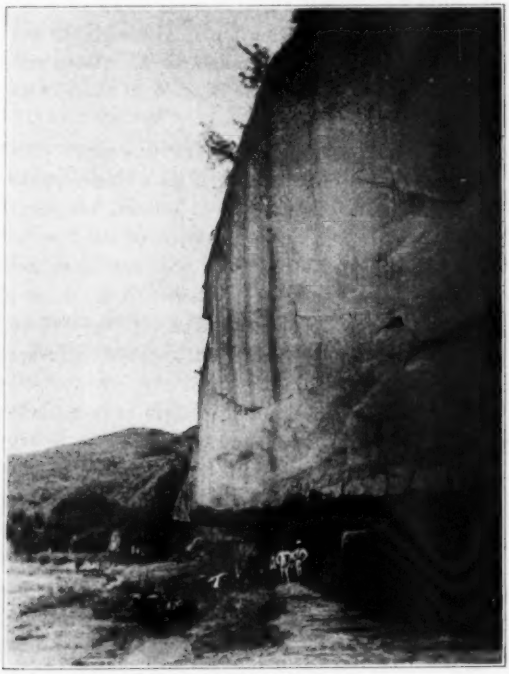


FIGURE 14.—*Cliff of massive Lo-ho Sandstone along the Lo-ho west of Yen-an-fu, Shen-si*

The sandstone face is false-bedded. The vertical markings are organic stains (photograph by Fuller).

miles along the river of the same name, in the region 25 to 35 miles southwest of Yen-an-fu (Fuller), and extending northward to the Great Wall and southward and southwestward a point beyond, to Pin-chou-hsien.

Character and thickness.—The formation in its typical development is a soft, massive, medium-grained sandstone, ranging from pinkish buff to light red in color, with separation planes often hundreds of feet apart, and even then of a character which leaves it in doubt whether they represent true or false bedding. The massive types sometimes give smooth vertical faces several hundred feet high without a trace of jointing or stratification other than false-bedding (figure 14). The dips of the latter are high, from 20 to 30 degrees and in various directions, resembling those of wind-drifted rather than water-deposited sands. The

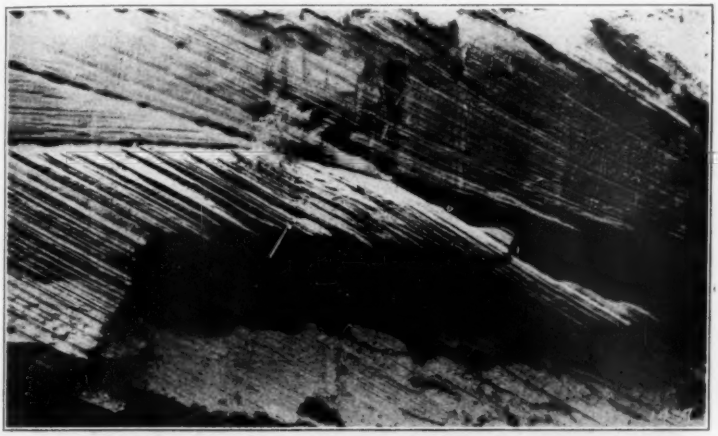


FIGURE 15.—*Details of Cross-bedding*

It is supposed to be of eolian origin in Lo-ho sandstone, on a headwater tributary of the Yen-shui northwest of Yen-an-fu, Shen-si (photograph by Estabrook).

general impression was of a prevailing drift from northwest to southeast (figure 15).

The formation as a whole dips westward, at a rate of not less than 50 feet per mile, for 20 miles, along the bed of Lo-ho and its tributaries, with an ascent of some 500 feet in the interval. This points to a thickness of not less than 1,500 feet and more probably of 2,000 feet. Above this the sandstones show the more regular bedding characteristic of aqueous deposition and are classed with the Hwa-chi.

Stratigraphic relations.—No marked differences in the inclination of the bedding of the Lo-ho and the underlying An-ting of I-chun were observed, but the change from marine limestone to eolian sandstone in the north, and from conglomerate to a sandstone in the south indicates a

break of importance, probably represented by a marked disconformity at the base. The change to the overlying Hwa-chi formation is essentially transitional, but with probable local disconformities.

Age.—The Lo-ho formation, so far as known, has yielded no fossils, and nothing is known of the age except that it overlies the An-ting formation, which the China Geological Survey places in the upper Jurassic. Since it antedates the Cretaceous peneplanation, it is presumably to be assigned to late Jurassic.

Description of exposures.—Where crossed, in the extreme northern part of Shen-si, a few miles south of the Great Wall, the formation is

FIGURE 16.—*Temple-capped Pinnacle of false-bedded Lo-ho Sandstone*

This pinnacle probably rises 600 to 800 feet or more above the Lo-ho at a point 50 to 60 miles west of Yen-an-fu, Shen-si, and near the top of the formation (photograph by Fuller).

described on the field maps of Estabrook and Barnett as "red sandstone" with little or no dip. Similar designations appear where the formation was crossed by the same geologists in the hills 10 miles west of An-ting, and again in a river valley 25 to 30 miles west of the same city. In the hills 15 to 20 miles west of Yen-an-fu it has the same massive character as in the Lo-ho Valley, the type locality, already described under character and thickness.

Many dwellings, consisting of one or more rooms with doors or win-

dows opening on the face of the cliffs, have been excavated within the soft sandstone in this region. The entrances seem to have been reached by ladders, but within stone stairways sometimes lead from one level to another. Few of the caves are now occupied, although the cutting of many has the appearance of being relatively recent. The weathering and rounding away of the sandstone about the openings of others, however, show great age. Some of the larger excavations may have been used as temples. Structural temples frequently surmount sandstone knobs or pinnacles of the formation and occasionally have subterranean chambers excavated in the rock (figure 16).

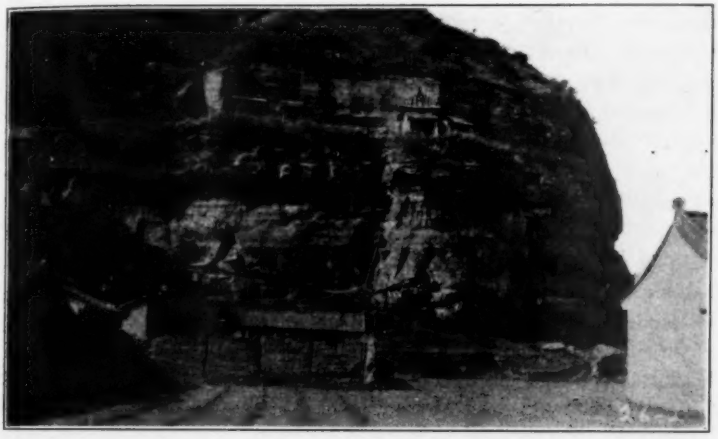


FIGURE 17.—*Lo-ho (?) Sandstone at Shui-hien-ting, near Pin-chou-hsien, Shen-si*

Showing typical cave-dwellings. False-bedding is inconspicuous and it is possible the formation is to be correlated with the Hwa-chi rather than with the Lo-ho (photograph by Estabrook).

Thirty miles west of Fu-chou the massive sandstone outcrops along the valley of the Tsing-shui for 15 miles in a straight line, to the Kan-su line. The dips appear to be from 1 to 2 degrees, pointing to a thickness, allowing for differences in level, of nearly 2,000 feet.

West of Tien-tou sandstone of the massive Lo-ho type forms a belt only 6 miles in width, pointing to a thickness of 1,000 feet, assuming a northwesterly dip of one degree, or 100 feet per mile, and an increase in elevation of 400 feet. The five miles of red shale outcropping in the river east of and below the typical massive sandstone mentioned are in line of strike with the basal Lo-ho beds on the Tsing-shui 25 miles to the north, while the alternating gray, green, and red beds outcropping west

of the massive sandstones are in line of strike with the upper portion of the Lo-ho beds near the Kan-su line on the same river. It would therefore seem that both the basal and upper portions of the Lo-ho formation have changed to shale between the Tsing-shui and the latitude of Tien-tou and I-chun, and it is possible that the massive character is largely lost beyond Pin-chou-hsien, although in the vicinity of this city fairly massive sandstones characterized by rock dwellings (figure 17) are still found.

HWA-CHI FORMATION

Name.—The name Hwa-chi, from the river in eastern Kan-su along which they outcrop, is applied to the regularly bedded red sandstones lying above the false-bedded Lo-ho sandstone and below the succeeding shaly Hwan-ho beds.

Character and thickness.—The exposures near the Shen-si-Kan-su line west of Yen-an-fu may be taken as the type locally. At ths point, above 2,000 feet of the false-bedded Lo-ho formation, the sandstones change to a normally bedded, water-deposited type, usually of a reddish color, outcropping in a belt more than 5 miles in width, with a probable thickness of 1,000 feet. A few of the sandstone beds exhibit recurrences of cross-bedding of the Lo-ho type. Occasional red shales are interbedded with the sandstones.

Stratigraphic relations.—The change from the Lo-ho to Hwa-chi deposition is rather abrupt, but there appears to be no discordance of dips other than with the false-bedding of the first-named formation. The change from the Hwa-chi to the Hwan-ho beds is by transition, marked by the appearance and gradual increase of shales.

Age.—The Hwa-chi formation is apparently to be referred to later Jurassic time and marks a return to aqueous deposition following the continental wind-blown deposition of the Lo-ho.

Description of exposures.—The character of the beds, as seen in the valley of the tributary of the Lo-ho near the Kan-su line, 50 miles west of Yen-an-fu, have been indicated under "Character and thickness." As in the Lo-ho formation, rock dwellings are common. The formation was noted, with similar character and thickness, along the Hwa-chi-ho and tributaries immediately west of the Kan-su line about 40 miles west of Fu-chou. As in the north exposure, the beds outcrop in a belt about 5 miles wide. They were not sharply distinguished from the underlying and overlying beds in the extreme north, nor south of the latitude of Fu-chou, where thick loess interferes with the tracing of the formation.

It is possible that the sandstone grades laterally into shale in the south, as was the case of the upper part of the Lo-ho formation.

HWAN-HO FORMATION

Name.—The term Hwan-ho is applied to the thick series of red sandstones and red, gray, or greenish shales lying above and west or northwest of the Hwa-chi sandstone, in the drainage basin of the Hwan-ho, in eastern Kan-su, from which the name is taken.

Character and thickness.—The formation is characteristically a thick series of alternating green and red sandstones and shales. There are in northeastern Kan-su three phases: a lower red sandstone phase, a middle zone of alternating red and green sandstones and shales in more or less equal proportions, and an upper phase of bright or apple-green shales and sandstones with very little red. The three phases and their approximate thicknesses, on the assumption of an average westward dip of 50 feet per mile for the first two and half that amount for the third, are as follows:

Hwan-ho formation (3,000 feet).		Feet
Hwan-hsien phase (top)	Bright greenish shales and sandstones	0–600
King-yang phase (middle)	Grayish, green, and red sandstones and shales	1,800–2,500
Tan-pa-li phase (bottom)	Red sandstones and shales	600

Stratigraphic relations.—There is no break of importance at the base of the formation, the contact being of a transitional character. The relations to the gypsiferous Tien-chi formation, supposed to be of later age, were not seen, but the contact is assumed to be essentially conformable.

Age.—This formation is placed in the Cretaceous by the Geological Survey of China,[46] but this correlation is almost certainly erroneous, since there is no break, but rather a gradual transition between the Hwan-ho and the underlying Hwa-chi of Jurassic age. In Mongolia, Cretaceous deposition always followed a long period of peneplanation of the Jurassic and older beds, and the deposits never grade into the latter or follow them conformably.[47] In eastern Kan-su the peneplanation did not precede, but followed, the deposition of the Hwan-ho formation, which is therefore retained in the Jurassic. Moreover, the firm, consoli-

[46] T. O. Chu: Bull. Am. Assoc. Petrol. Geols., vol. 9, 1925, p. 129.

[47] Charles P. Berkey and Walter Granger: "Later sediments of the desert basins of central Mongolia." Amer. Mus. Nat. Hist., Novitates, no. 77, 1923, pp. 16.

Charles P. Berkey and Frederick K. Morris: "Basin structures in Mongolia." Bull. Amer. Mus. Nat. Hist., vol. li, art. 5, 1924, pp. 103-27; "Structural elements of the old rock floor of the Gobi region." Amer. Mus. Nat. Hist., Novitates, no. 135, 1924, pp. 16; "Peneplanes of Mongolia," ibid., no. 136, pp. 11.

dated Hwan-ho beds have little resemblance to the uncemented sandy and gravelly beds of the Lung-chou or other known Cretaceous beds of the region.

Description of exposures.—The formation was crossed diagonally, from southeast to northwest, along the valley of the Lo-ho, etcetera, from west to east near King-yang-fu, and more or less parallel with the strike along the Kan-su-Shen-si border from west of Tien-tou to Lung-chou. In the Lo-ho Valley, as pointed out, the lower 1,000 feet is predominantly sandstone, many of the massive beds showing exfoliation caves and giving cliffs in which temples or dwellings have occasionally been excavated or pinnacles upon which temples have been built. The sandstones of this type often show a false bedding similar to that of the Lo-ho formation, but on a smaller scale. Considerable quantities of red shale and an occasional thin streak or bed of green or gray shale are interbedded with the sandstone.

The general dip is westward, at a rate of 50 feet or so per mile, but a distinct reversal, extending for several miles, gave a low anticline near the Shen-si-Kan-su boundary, 30 miles south of the most southerly bend of the Great Wall. This was the only broad and distinct structure recognized in the North Shen-si Basin outside the marginal areas.

Exposures continue in a northwesterly direction to within 30 miles of Ting-pien, beyond which even the 1,000-foot ravines in the loess fail to reach the rock. The dips here appear to be northwest rather than west and are usually less than half a degree. The beds are upturned locally along faults at one or more points. Northwest of Ting-pien, along the Great Wall, red sandstones and shales appear to form the desert floor beneath gravels and dunes.

The thickness of the lower, or Tan-pa-li, phase is not less than 600 feet and may reach 1,000 feet in the valley of the Lo-ho west of Yen-an-fu, but the sandstones die out rapidly to the south, being replaced laterally by red, gray, and green shales.

In the latitude of King-yang-fu the Tan-pa-li phase has disappeared, the King-yang phase coming in above the Hwa-chi a few miles west of the Shen-si-Kan-su line and continuing westward to a point 20 miles west of King-yang-fu, a distance of about 50 miles, which would indicate a probable thickness of 2,500 feet. The formation consists of red and green shales and sandstones in alternating zones, usually several hundred feet in thickness. The dips are wavy, with many minor rolls, those in upper beds sometimes being different from those 100 feet or so below. Numerous small faults occur, sometimes with local upturnings of the

beds. The general dip is apparently westerly at an average rate of not over half a degree.

To the northwest, up the valley of the Hwan-ho, sometimes locally known as the Ma-lien-ho, beds of the King-yang phase are seen for about 30 miles, beyond which is found what may be termed the Hwan-hsien phase, consisting of bright green sandy shales, applegreen shales, and sandstones, with a very few thin brick red to purplish layers. They outcrop for a distance of 40 miles along the river, but the actual width of the belt is considerably less. The dips are very low, being distinctly less than those prevailing farther east, and often too low to measure. They are, however, believed to be toward the west, at a rate of perhaps 25 feet per mile. Thick loess covers the region directly west of King-yang for 60 miles.

Seventy-five miles north, near the Great Wall, the beds forming the desert floor beneath the surface wash and dunes are largely reddish sandstones and shales, while near the Shen-si boundary, 80 to 90 miles south, they are of the King-yang red and green phase. The green Hwan-hsien phase is therefore of restricted extent, its position suggesting a late stage of basin filling.

Along the Kan-su-Shen-si line, extending southwestward on the north side of the Shen-si reentrant, the King-yang phase predominates. The dips in the region immediately west of I-chun are generally low, but farther southwest they become somewhat greater, commonly ranging from 1 to 2 degrees toward the northwest. West of Ling-tai the disturbance is greater, dips of 3 to 6 degrees being common, with inclinations of from 10 to 18 degrees locally, probably in the vicinity of relatively late faults. The dip of the beds is believed to change from northwest in the latitude of I-chun to north near Ling-tai and northwest near Lung-chou.

TIEN-CHI FORMATION

Proceeding along the Great Wall northwestward from the extreme tip of the Shen-si panhandle, the trails lead over deserts with dunes and superficial gravels through which red sandstones, probably of the Hwan-ho formation, occasionally show for a distance of about 10 miles from the Shen-si line; then climb to a low, gently undulating dune-capped mesa, or terrace, on which no rock was exposed, but fragments of gypsum, anhydrite, and limestone occurred at intervals for 15 to 20 miles. The gypsum apparently comes from beds above the red sandstones, but whether or not there is any break between the two was not determined.

Since the later Jurassic beds elsewhere carry traces of gypsum, while

evidences are wanting of the disturbance and erosion usually accompanying the formation of basins in which Cretaceous or later deposits were laid down in Mongolia, the balance of evidence seems to favor a Jurassic age for the Tien-chi gypsiferous beds. Little is known of their thickness, extent, or dip.

Cretaceous

General conditions

The land elevations resulting from the sharp Jurassic folding, which had already been greatly reduced before the close of that period, underwent further erosion and leveling in the Cretaceous, the resulting surface, if not a peneplain, being at least of an old-age character, with low monadnocks rising above broad shallow valleys in Shan-si, north Shen-si, and east Kan-su. This erosion stage, lasting from Middle Jurassic through the Cretaceous into the Tertiary, has been designated the Pei-tai physiographic stage by Willis,[48] who recognized it in the Wu-tai-shan of central Shan-si and elsewhere. In northwestern Shen-si and adjoining portions of Kan-su it is represented by the surface beveling to a common level the folded and faulted coal measures (Shan-si?) and the Jurassic sediments (figure 18). It has not been identified in the Tsin-ling or Ta-hua ranges on the south side of the North Shen-si Basin in central Shen-si, and the coarse nature of much of the material of the Lung-chou Cretaceous points to vigorous erosion on elevations of some magnitude in the vicinity. The limited development of the Cretaceous in eastern Asia as a whole seems to indicate that the amount of material removed during the early Cretaceous was not of large proportions.

Lung-chou gravels

Between the consolidated rocks and the base of the loess, especially in the vicinity of the higher mountain ranges, sandy and clayey gravels are found at many points. In most cases the gravels are of limited extent and grade upward through sands and sandy loess into normal loess, and are clearly of Tertiary age, but in west-central Shen-si, near the Kan-su line, they reach a considerable thickness and have yielded fossils indicative of Cretaceous age. To this body of gravels the writers have given the name Lung-chou, from the city near which they are best developed. They belong to the "Hua-ting facies" of the Liu-pan-shan series discovered in Kan-su by the Geological Survey of China.[49]

[48] Op. cit., vol. 1, p. 236, et seq.

[49] P. L. Yuan: Geological notes on eastern Kan-su. Bull. Geol. Society of China, vol. 4, no. 1, 1925, pp. 21-28.

At the type locality there are two series—an orange and a white. The "orange sands" were best seen in ascending southward up a small ravine to a pass situated about 10 miles northeast of Lung-chou. They are essentially a clayey sand or sandy clay of an orange, pink, brick red, or even blood-red color, with occasional green or white streaks a few inches thick. The grains are mainly quartz, but pebbles of acid crystalline rocks up to an inch in diameter occur. The bedding is mainly regular, but with cross-bedding locally. Some of the layers are cemented into sandstone beds several feet thick and beds of concretionary limestone are known.

South of the pass mentioned a white series comes in above the orange sands, capping the plateau to the east and south of the pass and leading around the ravines in continuous ledges with vertical faces and an inclination of 4 degrees to the south. The white gravel is a coarse conglomerate at the bottom, with pebbles of granite, schist, trap, porphyry, and limestone up to a foot or more in diameter. Above it becomes finer and somewhat pinkish or orange, but is not bright colored. Even the pink varieties tend to weather white. There is little cross-bedding. The contact with the underlying orange sands is sharp, but apparently conformable. Several faults occur southwest of the pass. The white gravels continue down the ravines to Lung-chou, 20 miles southwest of and 1,500 feet below the pass. The underlying older consolidated rocks are not reached by the stream. The combined thickness of the orange and white gravels can hardly be less than 1,000 feet.

P. L. Yuan, in the paper quoted above, states that in the northern Lung-hsien (Lung-chou) and Chien-yang (Kien-yang) districts "sandstones prevail," evidently referring to the Lung-chou gravels, which are unconsolidated or only partially cemented. His investigation of a locality reported to Fuller showed fish remains of Cretaceous age in a finely laminated limestone in a "group" of faulted blocks at Mo-chao-hsia, 23 miles northwest of Kien-yang.

The Lung-chou gravels represent confluent gravel fans and basin-wash deposited by more or less torrential streams leading from the high lands forming the adjacent rim of the North Shen-si Basin. The deposition took place in a long and relatively narrow trough extending northwestward along the east face of the mountainous western border of the basin mentioned in central Kan-su, and followed the early Cretaceous peneplanation of the Jurassic and certain of the older beds.

That beds of Cretaceous age may be found east of Kien-yang, possibly

as far as Lin-yu and Yung-shou, is suggested by the appearance of certain of the subloess gravels.

CRETACEOUS IN KAN-SU

According to Yuan, already quoted, Cretaceous beds, known as the Liu-pan-shan series, occur from Hai-yuan, Kan-su, on the north, to the region of Lung-chou and Kien-yang, Shen-si, on the south. He says:

"The strata are mainly composed of green, red, and white sandstones and blue and bluish green shales,[50] together with two oolitic limestones near the bottom and several layers of white and drab dense unfossiliferous limestones near the top."

The Cretaceous age was determined from plants, insects, and crustacea found at several localities.

The Kan-su Cretaceous beds are described as "rather faulted than folded, and usually dip toward the west, except where at smaller faults a short section dips eastward." They are apparently best developed "from Hao-tien, 25 li (8 miles) west of An-ko-chen, to Liu-pan-shan, 40 li (13 miles) farther west and form the high mountains at the latter place." The Lung-shan, on the other hand, includes older strata in addition to the Cretaceous.

TERTIARY

GENERAL CONDITIONS

As has already been stated, the Pei-tai stage of peneplanation, or old age erosion, continued through the Cretaceous into the early Tertiary. It was followed by a period of moderate uplift, a certain amount of warping, and some faulting, which led to a new stage of erosion, designated by Willis as the Tang-hien[51] physiographic stage in the Shan-si region and as the Tsin-ling[52] in the Tsin-ling and Ta-hua Mountains of southern Shen-si. The resulting surface was one of mature topography, with broad valleys, low divides, and hills or monadnocks ranging from 300 to possibly 1,000 feet in height. It is represented in the mountainous regions of Shan-si by remnants of valleys cut in the older Pei-tai surface, in southern Shen-si by the rounded contours of the surface antedating the Quaternary canyon cutting in the Tsin-ling and Ta-hua Mountains, and in northern Shen-si and east Kan-su by the valleys and elevations of the subloess rock surface found where the Pei-tai surface is not pre-

[50] Yuan's application of the terms sandstone and shale to the largely unconsolidated materials of the Lung-chou formation in Shen-si suggests that the Kan-su deposits may likewise be more properly designated as sands and clays, at least in part.

[51] Op. cit., vol. 1, p. 238 et seq.

[52] Ibid., p. 336 et seq.

served. It is considered by Willis as beginning in the early Tertiary and as continuing into the Pliocene, finally ending with the change of conditions which brought about the accumulation of loess of the Hin-chou stage,[53] beginning in late Pliocene. The climate, which during the Tang-hien-Tsin-ling stage appears to have been mild and humid and favorable to deep rock weathering, became relatively cold and arid in the Hin-chou stage, with the transportation and distribution of the products of decay by interacting water and wind and the beginning of their deposition as the earlier basal portion of the great loess mantle of Shan-si, Shen-si, and Kan-su.

GRAVELS

The greater part of the subloess sands and gravels around the rim of the North Shen-si Basin, where they are best developed, represent wash from the surrounding highlands. In the more central portions of the basin the wash was mainly from the higher parts of the somewhat uneven surface developed in the Tang-hien erosion stage. Some normal river accumulations may be represented. The material is essentially local in derivation and includes pebbles of Ki-chou limestone and Algonkian and Archean schists, gneisses, and granites in the vicinity of the rim, while in the central portion of the basin Shen-si fragments predominate. Considerable clay is present. The thicknesses range from 5 or 10 feet up to several hundred feet. At the top the beds usually become ferruginous and increasingly sandy and merge through reddish sandy loess into the normal yellow loess. Because of the local character of most of the beds and the thick cover of loess, it has been impracticable to attempt the correlation of the beds of one locality with those of another.

Accumulations of limited extent are found at many points along the west face of the mountains forming the east rim of the North Shen-si Basin in Shan-si. They may usually be described as soft, rusty, red sands and gravels, in some cases becoming interstratified with loess at the top. Occasionally they were seen in contact with tilted and beveled Shan-si or other beds. No evidence of their age other than that afforded by their position above the Tang-hien surface and below the loess was obtained by the writers in Shan-si, but the China Geological Survey, in cooperation with the Swedish Government, has recently found Pliocene or late Miocene fossils near Pau-te-chou, Shan-si, in what is described as "a deposit which contains a typical *steppe fauna*—for example, hipparions, giraffes, and antelopes."[54]

[53] Bailey Willis: Op. cit., vol. 1, p. 242 et seq.

[54] T. J. Ringstrom: Bull. Geol. Survey of China, no. 5, 1923, p. 93.

In Shen-si, coarse gravels consisting of pebbles of crystalline rocks locally cemented into conglomerates were seen beneath the loess at points along the face of the mountains south of the Hwang-ho and Wei-ho valleys. Yuan, in his paper on the Cretaceous, mentions "Red beds," which he refers to the late Tertiary as overlying the faulted Cretaceous and themselves block-faulted in the Lung-chou region. Rusty sands and gravels were noted beneath the loess around monadnock-like masses of the Shen-si formation, especially south of Yen-chang.

In Kan-su orange gravels with rounded pebbles were seen beneath the loess 15 to 20 miles west of the Shen-si line, in the latitude of Fu-chou. They are here referred to the Tertiary, but may be Cretaceous. Salmon-colored gravels and sands occur at various points in the Lo-ho region in Kan-su, 60 miles west of Yen-an-fu, Shen-si, grading upward into a red, clayey, and distinctly banded form of basal loess.

Yuan states:[55] "The prevailing red beds in Kan-su belong to the Tertiary age," but he neither states what is included under the term nor what distinguishes the "Red Beds" from the Permian, Jurassic, or Cretaceous beds of similar color. They are, however, said to be of wide distribution and to carry vertebrate fossils.

Brief mention of the "Red Beds" has also been made by C. Y. Hsieh.[56] J. G. Andersson, discussing the Kueite series of Loczy, says:[57]

"It seems beyond doubt that the red beds of the Kueite Basin, as well as all the way from Sinung to Lanchow, belong to the younger Tertiary, most probably Pliocene."

In the Ordos "post-Pontian" Pliocene was noted by Père Teilhard and Père E. Licent[58] at two points, near San-tao-ho and Tsung-choei-ying. The material is white fluvial sand carrying remains of fishes, turtles, crocodiles, mastodons, rhinoceros, hyenas, felis, rodents, etcetera.

QUATERNARY

GENERAL CONDITIONS

Beginning in early Quaternary times, Shan-si and southern Shen-si experienced a revival of orogenic disturbances. In west Shan-si the movement was chiefly one of uplift along the central part of the present mountain area of that region, with the development of numbers of more

[55] Loc. cit., p. 27.

[56] Bull. Geol. Soc. China, nos. 1-2, 1923, pp. 5-6.

[57] Geological notes from Kan-su. Bull. Geol. Soc. China, vol. 4, no. 1, 1925, pp. 15-18.

[58] On the geology of northern, western, and southern borders of the Ordos, China. Bull. Geol. Soc. China, vol. 3, no. 1, 1924, pp. 37-44. See, also, longer paper in French, quoted under Algonkian.

or less parallel fractures on the flanks, the blocks between the latter remaining as horsts or grabens. The west Shan-si mountain mass as a whole may, in fact, be likened to a single compound horst, limited on the east by the Ping-yang graben, lying between it and somewhat similar uplifted mass in east Shan-si, and bordered on the west by step faults which, combined with the normal westward dip, gradually lower the formations to the level of the relatively unaffected beds of the North Shen-si Basin.

The major dislocations have a north-south trend in northwestern Shan-si, but farther south they bend westward into Shen-si, where the disturbance is chiefly represented by the great fault along the north face of the Tsing-ling and Ta-hua Mountains, the Wei-ho graben to the north, and the faulted region immediately beyond.

The principal faults are commonly both curving and overlapping. Many of the fractures are branching or intersecting and not uncommonly pass into monoclinal folds at the ends. Practically all of the Quaternary faulting is of normal type. In west Shan-si the downthrows on the easterly side of the axis of uplift are chiefly to the east; on the westerly side they are mainly to the west or northwest. In Shen-si the downthrows are commonly to the north, but there are numerous exceptions.

The horst character of the mountains is perhaps best seen in the 'O-shan, north of the east-west stretch of the Fen-ho, above its mouth (figure 27). The west side of the equally striking Fen-ho graben is shown in figures 18, 22, 23, 27, etcetera. Minor horsts, grabens, tilted blocks, etcetera, are mentioned in the discussions of the formations or illustrated by the structure sections. The Wei-ho of central Shen-si flows above a downthrow block in front of the great fault-scarp mark-

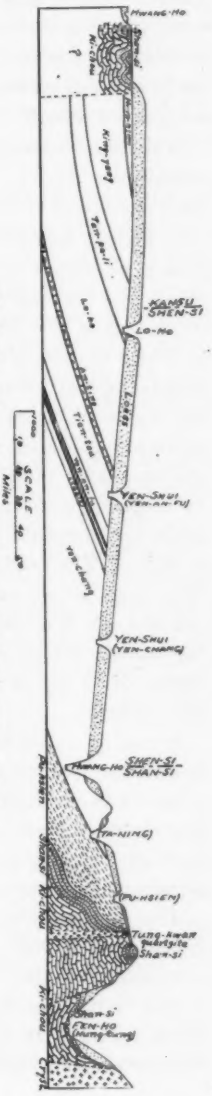


FIGURE 18.—*General Cross-section of the North Shen-si Basin From the Fen-ho, in Shan-si, to the upper Hwang-ho in Kan-su (Fuller).*

ing the north face of the Tsin-ling and Ta-hua Mountains (figure 5). The lower Fen-ho Valley, including the region on the south as far as the scarp of the Feng-huang-shan, is essentially of graben character and is a continuation of the Wei-ho depressed area (figure 28). The Hwang-ho, east of the acute bend at the southwest corner of Shan-si, flows above the lower edge of the tilted Feng-huang-shan fault-block in front of the scarp of a southerly branch of the Ta-hua-shan fault.

While the 'O-shan and other elevations represent horsts of considerable magnitude, many of the mountain masses coincide with anticlines, generalized sections of which (figures 19 to 28) seem at first sight to indicate that folding has played a greater part than faulting in creating the present elevations in west Shan-si. Since, however, it seems to be established that the region of the present mountains was reduced to a low relief during the Tang-hien (early and middle Tertiary) stage, and, furthermore, that little or no compression folding occurred in the Quaternary, it appears that the differences of elevation are best explained by movements on a considerable number of minor faults which, as explained, occurred on both sides of the mountainous area. As a result of the uplift and associated faulting, the mountains of west Shan-si are supposed to have reached their present altitudes of 6,000 to 10,000 feet or 2,000 to 5,000 feet above the relatively undisturbed areas within the North Shen-si Basin. The downward movement north of the Tsin-ling and Ta-hua Mountains in central Shen-si gave rise to the difference of elevation of nearly 7,000 feet between the Wei-ho plains and the mountain summits. The actual downthrow was considerably greater, as the surface of the sunken block lies at an unknown depth below the present loess and alluvial surface.

It may be of interest to note that the mountains of west Shan-si, although reaching the considerable altitudes mentioned above, did not prove a barrier to the distribution of the loess, but that comparatively little of this material passed over the lower mountains of east Shan-si. On the south of Tsin-ling and Ta-hua ranges proved an absolute barrier, hardly a trace of loess appearing on the southern slopes.

The minor faults found in the Jurassic sediments throughout the North Shen-si Basin appear in part to antedate the period of Cretaceous peneplanation and in part to be of Quaternary age. The block-faulting in the Lung-chou formation of the Cretaceous probably belongs to the latter period. On the west side of the basin the later faulting was not recognized, but probably exists. In general, however, the Quaternary

faulting on the west and north sides of the basin appears to have been less than on the east and south.

The southeastward slope of the rock surface, developed in the Tanghien stage (early and middle Tertiary) and now found beneath the loess of the North Shen-si Basin, as described under topography, may be due in part to Quaternary tilting; but, since its slope coincides rather closely with the drainage of the stage mentioned, it is probable that its inclination is in part the result of normal erosion processes. Wind seems to have played the most important part in production of the slope of the loess plateau.

The period of faulting, which has been designated the Fen-ho (Fön-ho) physiographic stage by Willis,[59] covers the whole Quaternary. Numerous minor and some pronounced post-loess dislocations are found, some of which have occurred during historic times, as that giving rise to the Kan-su earthquake of 1920. Certain of the loess scarps on both the north and south sides of the Wei-ho Valley may be the result of Recent faulting. The modification and constant shifting of the superficial portion of the loess, which is still going on, has, however, caused the obliteration of most of the post-loess scarps.

During all of the earlier part of the Fen-ho stage the arid conditions inaugurating the Hin-chou stage of loess transportation and accumulation in the later Pliocene continued with little change and resulted in the deposition of from 500 to 1,500 feet or more of the Huang-tu, or loess, formation, but the Hin-chou stage is regarded as ending with the beginning of the Fen-ho disturbances. The early Recent time saw a change to more humid conditions and the erosion of both loess and underlying rock. Following a stage in which the eroded loess surface became well rounded, a rejuvenation took place, resulting in the present sharp gullying. This change probably took place within historic times, and the resulting erosion is still proceeding actively.

PRE-LOESS GRAVELS

While some of the subloess gravels are Cretaceous or Tertiary, many of the deposits are probably of Quaternary age. De Chardin and Licent report gravel terraces below the loess around the elevations of the western Ordos and mention fluvial or eolian sands carrying Quaternary mammalian bones which pass into the "fresh-water" loess near Yu-lin-fu, in northern Shen-si.[60]

[59] Op. cit., vol. 1, p. 256.
[60] Bull. Geol. Soc. China, vol. 3, no. 1, 1924, pp. 37-44.

Prominent gravel benches were noted by Fuller on the east side of the Hwang-ho Valley near Ling-chou, in northeastern Kan-su. The materials were mostly very coarse and included many limestone and crystalline fragments, some several feet in diameter, presumably derived from the Ala-shan a few miles to the west. These deposits were assigned to the Quaternary in the field, but may be older. The surface is often covered by loess and sand, but it is possible that much of this may be of comparatively late Pleistocene or even Recent deposition.

In the North Shen-si Basin as a whole the earlier Quaternary gravels are represented chiefly by cobble, pebble, or sand zones in the loess. Sharp erosion unconformities often separate this basal zone from the impalpable overlying loess.

LOESS

The tremendous thickness of the loess of the North Shen-si Basin, in or near which it reaches its maximum development in China, and the number and complexity of its problems of origin, distribution, topography, and geologic and physiographic history are such as to warrant more extended treatment than is here possible. The writers have therefore reserved the detailed discussion of the loess for a future paper and limit themselves at this time to a few general statements.

To the loess, with its interbedded sands or gravels, the term Huang-tu has been applied by Willis.[61] Usually the extraneous materials occur only near the base, the great bulk of the formation consisting of the normal impalpable silt exhibiting the characteristic vertical cleavage. Banding, sometimes of a reddish color suggesting soil zones, is occasionally seen. Concretions sometimes occur in horizontal planes near the base. Fossils are comparatively rare and when found are of land species.

The loess material is supposed to have been derived from Mongolia and central Asia and to be a product of rock weathering, no regional glaciation such as has afforded loess in other regions having occurred. The distribution was by interacting wind and water, the Hwang-ho being the principal aqueous carrier. The accumulation began in late Tertiary and was essentially completed in late Pleistocene. Although loess is still shifting, no important addition to its mass as a whole is now going on.

The general distribution, relations to underlying formations, and relief of the loess have been outlined under "Topography." Since the upper surface of the loess in most places has the form of a plateau, it follows

[61] Op. cit., vol. 1, pt. 1, p. 183.

that the thickness will vary with the relief of the buried topography. That it is often over 1,000 feet thick is shown by the fact that ravines of that depth fail to reach the rock beneath. Elsewhere, however, the rock may project through the loess as monadnocks. The thickest loess observed was in northwest Shen-si and in eastern Kan-su, where it locally reaches a thickness of 1,500 and possibly 2,000 feet. A thickness of 500 feet is, however, a fair average for much of North Shen-si. In Shan-si it is still less. Erosion greatly reduces the thicknesses along all streams, or even cuts through it into the underlying rock.

RECENT DEPOSITS

Gravels on loess.—The best examples of gravels on loess were found in the region northwest of Lin-yu, in west-central Shen-si, where exposures of salmon-pink gravels with pebbles from 1 to 6 inches, with a few boulders up to 3 feet in diameter, were noted at the tops of the loess ridges at altitudes of nearly 5,000 feet. The pebbles were mostly granite, but quartzite, cherty limestone, and schists were represented. The granite fragments were rotten. Except the limestone, which may have come from a local elevation a few miles to the south, the materials appear to have been derived from the mountains south of the Wei-ho.

Dunes.—The presence of dune sands on the loess surface is a conspicuous feature along the Great Wall, in Shan-si and Shen-si. The dunes, which are best developed west of the Hwang-ho, have a little vegetation in places, but there are considerable areas of bare and desolate white sand in great rolling, wavelike billows resembling those of the Sahara, but less regular than the "sand ridges" of Western Australia.

Loess-flows.—At times, especially following heavy and sudden downpours of rain, the loess cliffs collapse and form dams across the smaller valleys, behind which temporary lakes collect. In Kan-su, somewhat west of the area under discussion, the earthquake of 1920 caused great masses of loess to become detached from the hillsides and to disintegrate and flow, like a thick fluid, in great tongues for a distance of a mile or more outward on the level bottoms of the wider valleys. Willis attributed the presence of great boulders on the flats fronting the Ta-hua-shan, 3 miles east of Hwa-chou and 25 miles west of the Hwang-ho, at its acute eastward bend, at the southwest corner of Shan-si, to such a flow, the boulders of the talus at the inner margin of the loess terrace having floated outward onto the plain on the collapse of the latter.[62]

[62] Op. cit., vol. 2, p. 251.

Floodplains.—Floodplains are usually absent along the Hwang-ho, which is nearly everywhere in a gorge, the bottom of which it is still cutting. The lower and upper portions of most other streams are likewise cutting, but in the middle portions of their courses the streams are often locally flowing at grade and have floodplains of moderate widths. The Wei-ho, as has been mentioned, is aggrading its valley, which lies over a fault-block which appears to have sunk in part in comparatively recent times (figure 5). The Fen-ho, probably for a similar reason, is likewise aggrading in the region near its mouth and again, beyond an intervening gorge, in central Shan-si.

Stream gravels and tufa.—The stream gravels in the ravines cutting through the loess into the rock are often cemented into conglomerates, especially in the vicinity of springs from the Ki-chou limestone in west Shan-si. Tufa deposits, or mixtures of conglomerate and tufa, were noted at several points. In places the gravels or conglomerates have been more or less buried by loess of Recent deposition.

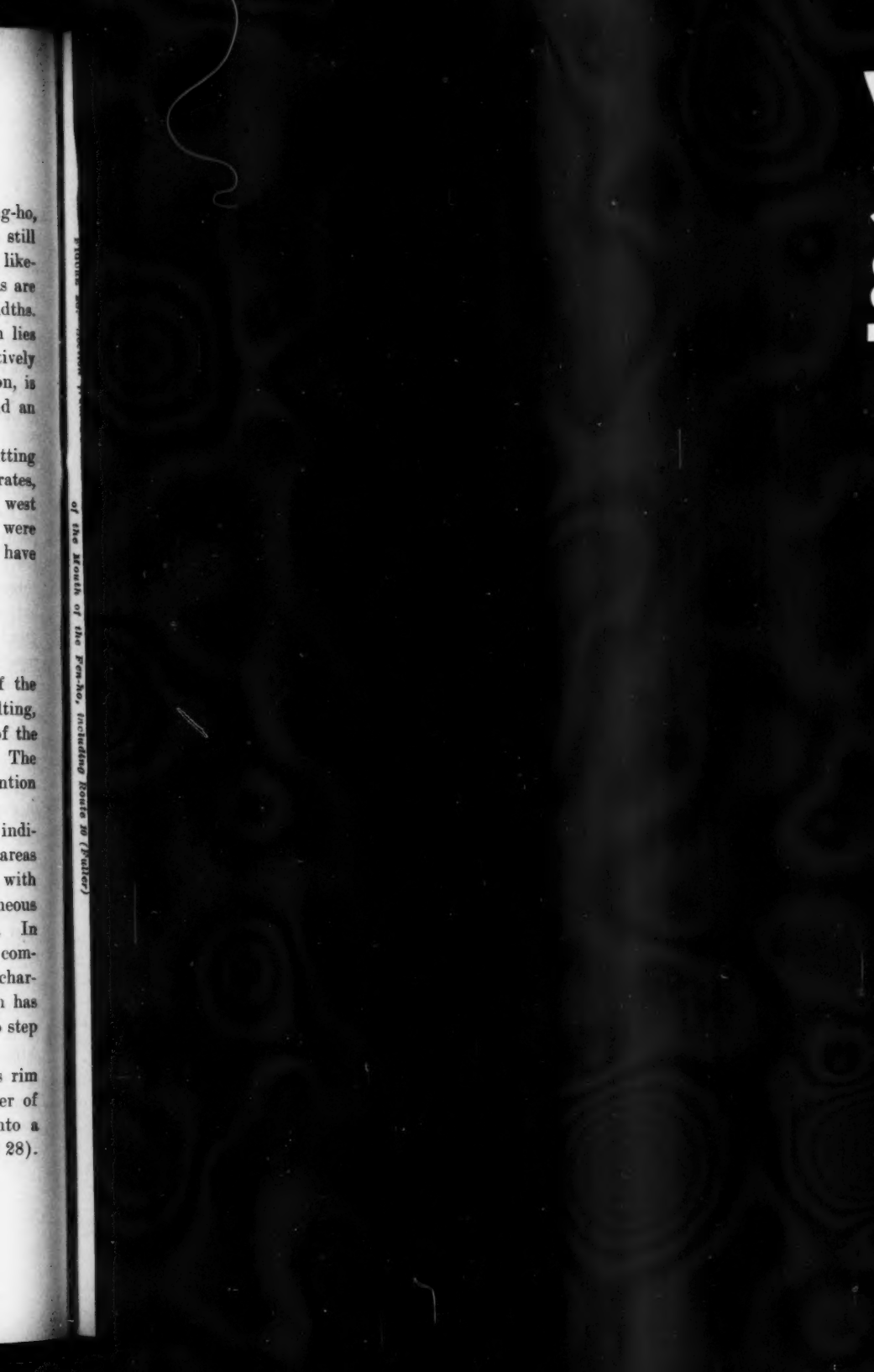
Structure

North Shen-si Basin

The general structure of the North Shen-si Basin and that of the surrounding area, as well as the local attitude of the beds, faulting, etcetera, has been incidentally touched upon in preceding sections of the text, chiefly in connection with the descriptions of the formations. The structure may, however, be briefly reviewed at this point and attention called to the principal features.

The location, size, and general relations of the basin have been indicated in the "Introduction" of this paper. The mountainous areas surrounding it on all sides are regions of pronounced disturbance, with sharply folded and faulted sedimentary rocks with occasional igneous intrusions from Archean or Algonkian to early Mesozoic in age. In addition to a minor number of thrust-faults associated with the compression folding, the west Shan-si and central Shen-si regions are characterized by both ancient and relatively late normal faulting, which has given rise to a number of important grabens and horsts as well as to step faulting.

On the inner side of the disturbed areas constituting the basin's rim on the east and south, the basin beds proper dip toward the center of the trough through a succession of decreasing folds, merging into a monocline at 25 to 30 miles from the basin boundary (figures 19 to 28).



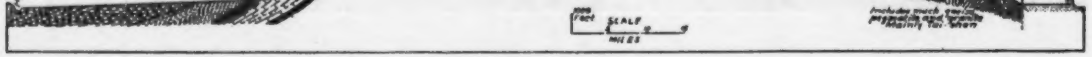


FIGURE 21.—*Section along Route 3, Shan-si, from Sin-chou through Ko-tan-chou and Sing-ho to the Hwang-ho (Estabrook)*

FIGURE 22.—*Section along Route 4, Shan-si, from Tai-yuan-fu through Lin-hsien to the Hwang-ho (Barnett)*

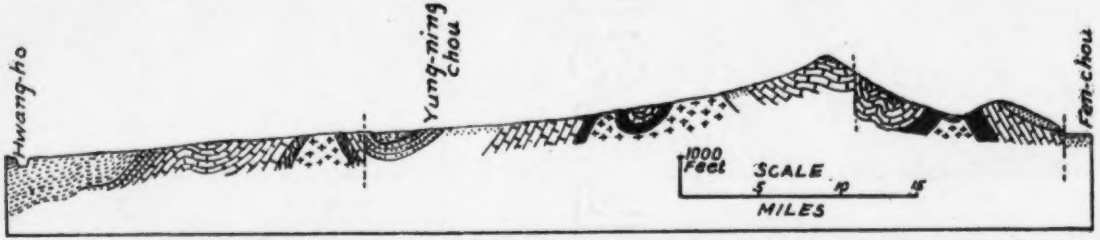


FIGURE 23.—*Section along Route 5, Shan-si, from Fen-chou through Yung-ning-chou to the Hwang-ho (Fuller and Barnett)*

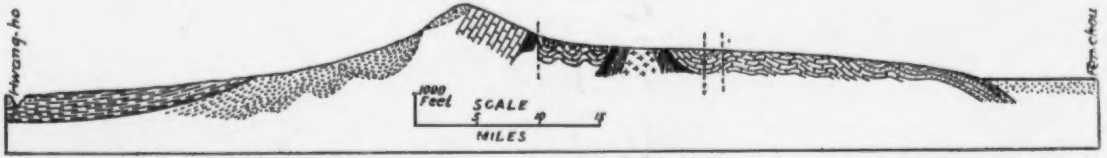
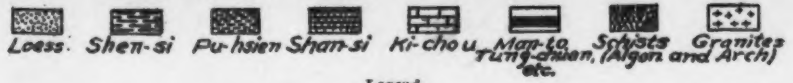


FIGURE 24.—*Section along Route 6, Shan-si, from Fen-chou to the Hwang-ho opposite the Mouth of the Yi-ho (Fuller and Barnett)*



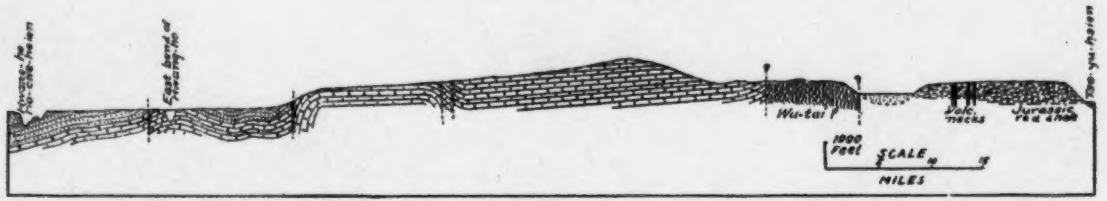


FIGURE 19.—*Section along Route 1, Shan-si, from Tso-yu-hsien to the Hwang-ho at Ho-che-hsien (Estabrook)*

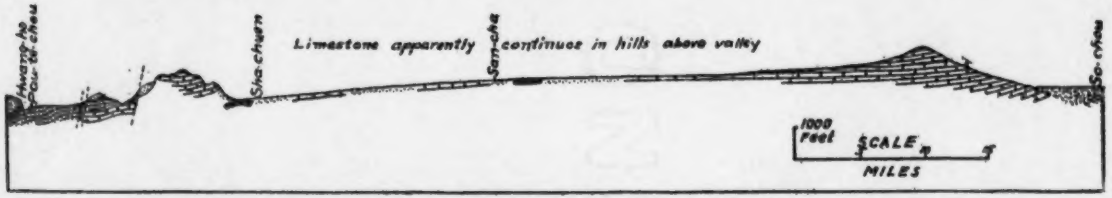


FIGURE 20.—*Section along Route 2, Shan-si, from So-chou to the Hwang-ho at Pao-te-chou (Clapp)*

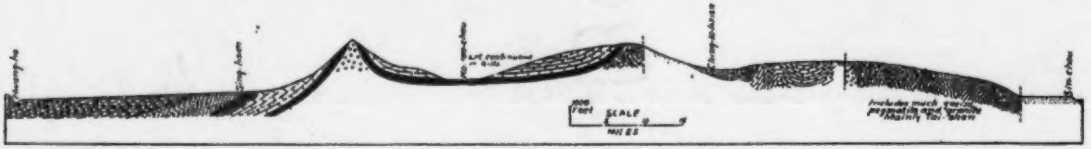


FIGURE 21.—*Section along Route 3, Shan-si, from Sin-chou through Ko-tan-chou and Sing-ho to the Hwang-ho (Estabrook)*

FIGURE 25.—*Section along Route 7, Shan-si, from Fen-chou through Si-chou to the Hwang-ho (Clapp and Fuller)*

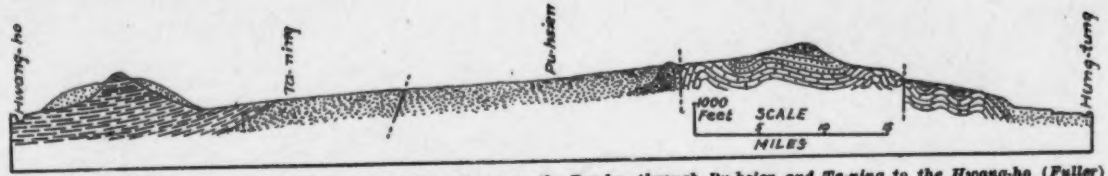


FIGURE 26.—*Section along Route 8, Shan-si, from Hung-tung, on the Fen-ho, through Pu-hsien and Ta-ning to the Hwang-ho (Fuller)*

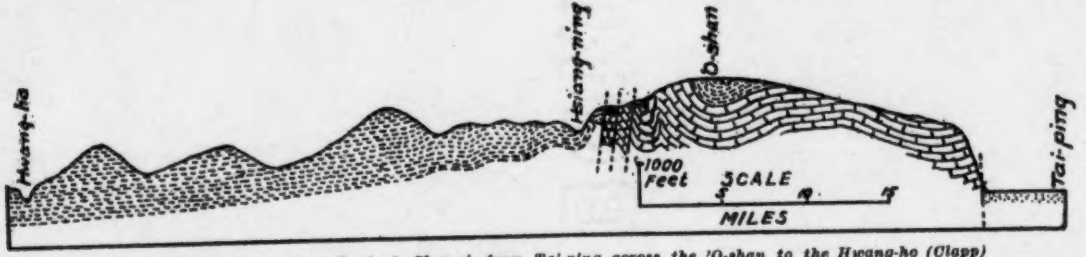


FIGURE 27.—*Section along Route 9, Shan-si, from Tai-ping across the 'O-shan to the Hwang-ho (Clapp)*

FIGURE 28.—*Section from Ta-hua-shan, near San-chou, Honan, northwestward across Southwest Shan-si to the Hwang-ho north of the Mouth of the Fen-ho, including Route 10 (Fuller)*

The usual inclination from this point to the western limits of the basin is from one-half to one degree, with an average of 50 feet per mile, the formations successively dipping beneath the surface until 15,000 feet of beds, ranging from Carboniferous to late Jurassic in age, have disappeared.

On the western rim of the basin in east Kan-su beveled coal-measures appear beyond an intervening area of thick loess at the level of the flat Upper Jurassic a few miles to the east, while limestone (Ki-chou?) is found in tilted masses of higher elevation. Since the Jurassic beds do not appear to be repeated, the inference is that they abut against a fault-plane of considerable throw.

No details are available as to the marginal structure of the basin in the Ordos region, but the position and trend of the tilted Paleozoic and older rock masses north of the Hwang-ho suggest conditions similar to those of Shan-si.

The general cross-section of the basin (figure 18) shows the structure along a line from Hung-tung, on the Fen-ho, in south-central Shan-si, to the upper Hwang-ho, in Kan-su, at a point northwest of the northwestern arm of Shen-si, bringing out the Fen-ho graben, the Ying-shan horst, the folds of the eastern margin of the basin, the monoclinal to flat dips of the central and western parts, and the supposed western relations of the basin beds. Figure 5, compiled from maps of Estabrook and the reports of Willis, extends from the summit of the Tsin-ling-shan, in central Shen-si, northward across the Wei-ho graben and the faulted region between Yao-chou and Tung-kwan-hsien to the less-disturbed area north of the latter city.

WESTERN SHAN-SI STRUCTURES

Figures 19 to 28 show cross-sections along routes 1 to 10 which extend from the Fen-ho Valley, or from the same longitude in the region to the north, westward to the Hwang-ho. The section for Route 10 has been extended southeastward across the Fen-ho and lower Hwang-ho to the mountains south of Shan-chou, Ho-nan (figure 28). These sections bring out the complexity of the region regarded by Richthofen as approximately horizontal and essentially continuous Carboniferous and Permian beds. It is believed that the sections are fairly accurate, though necessarily generalized, in spite of the fact that the original notes are unavailable for several of them. It should be noted, however, that faults are much more frequent than can be indicated on sections of small scale. In many cases the movement has been too small to affect the

general structure, but elsewhere faults of considerable magnitude may occur, especially within the thick masses of Ki-chou limestone, where they are often recognized with difficulty. In general the downthrows on the east side of the principal axis of disturbance, commonly marked by an Archean or Algonkian core, are toward the east, while on the west side the drops are prevailingly toward the west. There are, however, numerous exceptions, and blocks standing as horsts above adjacent graben blocks are not uncommon. Because of this, although the folding is usually more conspicuous than the faulting, the basins of the region are spoken of, for convenience, as grabens. The faulting has been further discussed in the section on the Quaternary.[62]

It has seemed inadvisable, with the limited data at hand, to attempt the differentiation of the Archean and Algonkian in the sections, in which the general character rather than the age of these rocks are indicated. The more conspicuously banded gneisses are usually included with the schists, while the more massive are included with the granites.

The sections show the profiles of the routes traveled, often in valleys and over low passes; hence do not show the true altitudes of the mountain masses, of the heights of which only meager data are available.

Geological Map

Because of the considerable intervals between the geological traverses, and especially the unavailability of original notes in many localities, the geological map must be regarded as of a reconnaissance type. Where the structure is regular and the beds fairly sharply defined, as in western-most Shan-si, most of northern Shen-si, and in eastern Kan-su, the extent and limits of the formations are shown in full, but around the edge of the basin on the east, south, and west, where the structures are more complicated, as well as often hidden by thick loess, the correlation of the outcrops encountered on the various traverses are so uncertain that it has seemed desirable to map only what was actually observed. Too little is known of the extent of the Cretaceous and Tertiary to warrant any attempt at mapping.

The fact that the separation of the formations is in part based on color, and that contacts are often transitional, leads to certain inaccuracies in

[62] The Geological Survey of China is said to have a report on Shan-si in preparation, and an advance summary has been published by C. C. Wang (Bull. Geol. Society of China, vol. 4, no. 1, 1925, pp. 67-80), in which the principal folds and faults have been named and mapped and cross-sections given. Although the chief structural lines agree with those recognized by the writers, it is difficult to harmonize many details of the sections with those of the present paper.

detail, which, however, are not important on a map of the scale used. Other inaccuracies necessarily follow from the lack of any detailed base map and the consequent impossibility of correctly adjusting boundaries to topography except in a general way. The lateral changes in the characteristics of the Shan-si and Pu-hsien formations and their approach toward the Shen-si formation in composition in west-central Shen-si introduces a further element of uncertainty in the mapping of this region, in which the loess is also unusually thick. The same is true of the lateral transitions in all the Jurassic formations above the Shen-si. Attention is called to the fact that the trend of the limestone pattern does not necessarily indicate the strike of the beds.

CONCLUSION

The results of a stratigraphic investigation of a new region such as that covered by the present paper are best summarized in the geological column, map, and sections. An outline of the principal features brought out by the studies has been given under "Results of investigations" in the "Introduction" and need not be repeated.

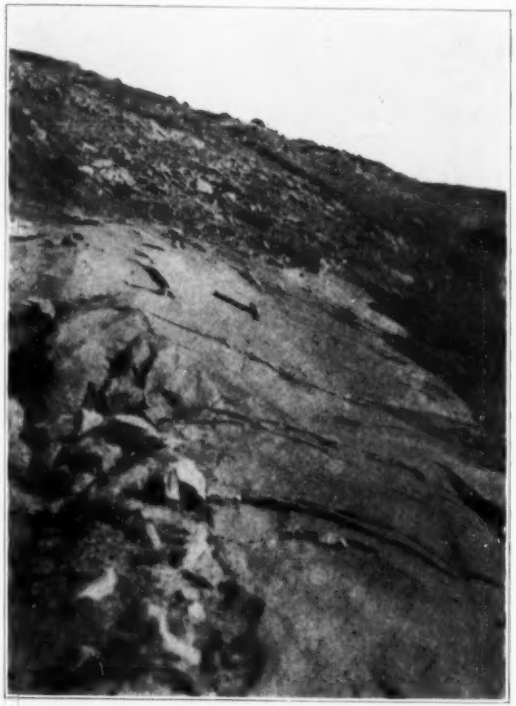


FIGURE 1.—EXPOSURE OF PERMO-CARBONIFEROUS TILLITE AND STRIATED PAVEMENT AT HALLETTS COVE, NEAR ADELAIDE, SOUTH AUSTRALIA

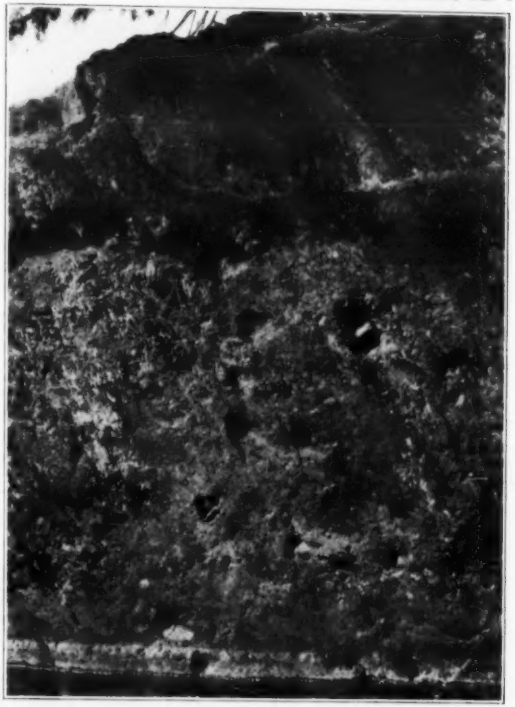


FIGURE 2.—EXPOSURES OF PRE-CAMBRIAN TILLITE ON STURT CREEK, NEAR ADELAIDE, SOUTH AUSTRALIA

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NEW TILLITE LOCALITY IN WESTERN AUSTRALIA[1]

BY FREDERICK G. CLAPP

(Presented before the Geological Society December 28, 1926)

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INTRODUCTION

At least four pre-Pleistocene glacial epochs are known to have occurred in Australia, being of pre-Cambrian, Cambrian, Permo-Carboniferous, and probable Upper Cretaceous ages respectively.

Much work has been done by Professor David[2] on this subject and he has ably summarized the existing knowledge.[3]

In Australia pre-Cambrian tillite was first proved in 1902 by Howchin,[4] but he considered it as of Cambrian age. It is conspicuous in

[1] Manuscript received by the Secretary of the Society January 8, 1927.

[2] Sir T. W. Edgeworth David: Address of the President to Section C, Geology and Mineralogy. Aust. Assoc. Adv. Sci., Brisbane, 1895, 41 pp., 3 pls.

Discovery of glaciated boulders at base of Permo-Carboniferous system, Lochinvar, New South Wales. Jour. and Proc. Roy. Soc. N. S. W., vol. XXXIII, 1899, pp. 154-159, 1 pl.

The Permo-Carboniferous glacial beds at Wynward, near Table Cape, Tasmania. Aust. Assoc. Adv. Sci., 1907, 10 pp., 2 pls.

With Ralph Tate and Walter Howchin: Report of the Research Committee appointed to collect evidence as to glacial action in Australasia. Aust. Assoc. Adv. Sci., Brisbane, 1895, 6 pp., 2 pls.

With Walter Howchin: Notes on the glacial features of the Inman Valley, Yangaillia, and Cape Jervis District. Trans. Roy. Soc. S. A., 1897, pp. 61-67.

With C. A. Sussmilch: Sequence, glaciation, and correlation of the Carboniferous rocks of the Hunter River District, New South Wales (with appendices by A. B. Walkom and W. R. Browne. Jour. and Proc. Roy. Soc. N. S. W., 1920, pp. 246-338.

[3] Conditions of climate at different geological epochs, with special reference to glacial epochs. Printed by Secretaria de Fomento, Mexico, 1907.

[4] Walter Howchin: Trans. and Proc. Roy. Soc. S. A., vol. XXV, 1901, p. 10; Proc. Aust. Assoc. Adv. Sci., Hobart, 1902, pp. 198,200.

Sturt Creek, 7 miles southeast of Adelaide, South Australia (plate 9), and it is said to be in places 300 to 900 feet thick. Tillite of Lower Cambrian age is known at a number of localities in Australia and may have been contemporaneous with the Nan-t'ou tillite described by Willis[5] in the Yangtze Kiang Valley of central China. Tillites of Permo-Carboniferous age are of widespread occurrence in New South Wales, South Australia (plate 9), Queensland, and in Kimberley and Northwest divisions of Western Australia.

Lyons Conglomerate of Western Australia

The Lyons conglomerate, or principal known glacial deposit of Western Australia, and its phenomena have been described in detail by Gibb Maitland, having been first discovered by him in 1897.[6] This formation lies near the contact between the so-called "Upper Series" and the "Lower Series," of Permo-Carboniferous age. The conglomerate is exposed almost continuously throughout a belt crossing the valleys of Gascoyne, Minilya, Lyndon, Wooramel, and Irwin rivers, in Northwest and Southwest divisions. It extends through a north-south distance of at least 400 miles, from a point 150 miles northeast of Carnarvon to within 200 miles north of Perth (figure 1). It is a magnificent bed of heterogeneous, glaciated and frequently perfectly striated boulders, some of which are 10 feet or more in diameter (plate 10). Gibb Maitland considers the deposits as contemporaneous with the Dwyka conglomerate of South Africa, the Talchir conglomerate of India, the Orleans conglomerate of Argentina and southern Brazil, and with various Permo-Carboniferous tillite deposits of eastern Australia. In 1910 or 1911 he predicted the possible discovery of a representative of the Lyons conglomerate in latitude 16° or 17°, in Kimberley District, 700 miles northeast of the farthest northeast known exposure on Lyndon River, and since that time some good exposures of such tillite have been found in the region designated.

Upper Cretaceous Tillite

The presence of an Upper Cretaceous glacial epoch in Australia was first suggested by Brown in 1894.[7] He had found numerous erratic

[5] Bailey Willis: Research in China, vol. II, Rept. Carnegie Institute of Washington, 1907, pp. 39-40.

[6] A. Gibb Maitland: Relics of the Permo-Carboniferous Ice Age in Western Australia, being the anniversary address of the President, delivered July 11, 1911. Jour. Nat. Hist. and Sci. Soc. W. A., vol. IV, Perth, 1911, 22 pp., 15 figs.

[7] H. Y. L. Brown: Ann. Rept. of Govt. Geologist S. A., 1894, p. 10.

FIGURE 1.—LYONS CONGLOMERATE APPEARING AS A DOME 14 MILES EAST OF MOOGOORIE HOMESTEAD, 150 MILES NORTHEAST OF CARNARVON

FIGURE 2.—LYONS CONGLOMERATE OUTCROPPING 150 MILES EAST OF CARNARVON

TYPICAL EXPOSURES OF LYONS CONGLOMERATE—A PERMO-CARBONIFEROUS TILLITE OF WESTERN AUSTRALIA

FIGURE 1.—*Map of Western Australia showing known Tillite Localities.*
P and *PP* are outcrops of Permo-Carboniferous tillite; *C* and *C* are outcrops of tillite of probable Upper Cretaceous age.

blocks of large size in a formation of this age in South Australia. Their origin has been debated, but has more recently been proved rather definitely. Tillite that includes striated erratics of undoubted post-Lower

Cretaceous age is reported by the Glacial Research Committee[8] to occur near Dalhousie, between Lake Eyre and the Macdonnell and Everard ranges, in approximate latitude 26° 25′ south and longitude 135° 30′ east. This tillite has been described as existing in Finke Valley, in latitude 26° south, longitude 134° 5′ east, on the boundary between South Australia and Northern Territory, visited by Professors Tate and Baldwin Spencer in 1894[9] and described by Tate and Watt.[10] The age was originally assigned to the "Permo-Carboniferous or Later."

In 1912 Talbot discovered,[11] in the Princess Range near Lake Carnegie, in latitude 26° 30′ south and longitude 122° to 123° east, a deposit of tillite containing large boulders of gneiss, granite, porphyry, quartzite, etcetera, embodied in clay and resting unconformably on the Nullagine series. The general relations were such that this deposit seemed to be of Cretaceous age and was named by him the Wilkinson Range beds (figure 1).

Recently discovered Tillite

The tillite discovered by the writer of this paper is exposed near Braeside Homestead, an outstation of Warrawagine, situated on Oakover River, a tributary of De Grey River, about 200 miles southeast of Port Hedland and 400 miles north-northeast of Meekathara. The specific locality is 2 miles north of Braeside, on the motor road from Warrawagine (figure 1). Good exposures form gentle slopes covering several acres and rising 15 feet or more above the road. They consist of light-colored sands or clays crowded with assorted subangular pebbles which range in composition from unclassified sandstones to granites and quartzites. Specimens are now in the possession of the University of Sydney. On examination many of the granitic pebbles were found to be entirely kaolinized, while others are so fresh that distinct glacial scratches are discernible on them.

Provisional Correlations

So far as its environment is concerned, the tillite might be of almost any age from Cambrian to Tertiary, and nothing definite as to this could

[8] Sir T. W. Edgeworth David and Walter Howchin: Rept. Aust. Assoc. Adv. Sci., vol. XVI, 1923, pp. 74-94. Wellington, N. Z. (1924.)

[9] Report on the occurrence of glacial boulders at Yellow Cliff, Crown Point Station, Finke Valley, Central Australia. Aust. Assoc. Adv. Sci., Sydney session, January, 1898, 6 pp., 1 pl.

[10] Report Horn Scientific Expedition to Central Australia, Part 3, Geology and Botany, p. 72, London and Melbourne, March, 1896.

[11] H. W. B. Talbot: Geol. Surv. W. A., Bull. 83, 1920, pp. 59-60, fig. 16, and frontispiece.

be learned at the time from the stratigraphy, for fossils were not found near by. The underlying country rocks are believed to be of early Paleozoic age, but a few thousand feet west a tableland stands about 100 feet above the valley, extending south for scores of miles and similar to many tablelands in the western part of Desert Basin, which may be of Permo-Carboniferous, Jurassic, or Tertiary age.

The fact that the tillite lies at a lower level than the tableland may favor a Permo-Carboniferous age. On the other hand, its lithologic character and position are different from any Australian Permo-Carboniferous tillite known to the writer. It appears similar in character to the Finke Valley tillite as described, has many points of resemblance to that in the Macdonnell ranges, and may be a western representative of the Wilkinson Range tillite beds found by Talbot, 350 miles to the southeast.

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PROCEEDINGS OF THE PALEONTOLOGICAL SOCIETY

FOSSIL FOOTPRINTS FROM THE PENNSYLVANIAN SYSTEM IN OHIO[1]

BY J. ERNEST CARMAN

(Presented in abstract before the Paleontological Society Dec. 29, 1926)

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INTRODUCTION

Two large slabs showing fossil footprints were collected many years ago by Dr. Edward Orton and placed in the Geological Museum of Ohio State University. Recently another large slab showing fossil footprints has been obtained for the same collection. It is the object of this paper to describe the footprints shown on these three slabs. Footprints have been recorded from the Pennsylvanian system from Pennsylvania, Indiana, Illinois, Missouri, and Kansas and more extensively from Nova Scotia, but so far as known none has been fully described from Ohio.[2]

Each of the slabs here described shows a consecutive series of footprints of fore- and hindfeet and of right and left feet—a total of fifteen or more footprints on each slab. This is important because there is con-

[1] Manuscript received by the Secretary of the Society March 24, 1927.

[2] In 1924 Prof. G. F. Lamb spoke briefly before the Geological Section of the Ohio Academy of Science on "An amphibian trail from Pottsville formation," based on some slabs in the collection at Mount Union College. The tracks were not identified or named and nothing concerning them has been printed. From a picture of one of the slabs the tracks apparently belong to the genus Hylopus. They are much smaller tracks than those described in this paper. The tracks mentioned by Prof. J. L. Tilton in footnote 7, p. 387, vol. 37, Bulletin of the Geological Society of America, are the ones described in this paper.

siderable variation within any series and the most complete ones can be used as the correct footprints. Many of the earlier descriptions of ichnites or fossil footprints are useless for identification purposes because based on one or two tracks that may be incomplete or not typical. The three slabs show different tracks, and a search of the literature on ichnites has shown that they are not described. It is, therefore, necessary to establish new species for all three of them and new genera for two of them.

Up to the present, ichnites have not been used to any degree for geological correlation, but possibly if they were better known and more accurately described and figured they might in some cases be of value for correlation purposes, especially since those strata that contain ichnites are commonly without other fossil remains.

Baropus hainesi, new Species

PLATE 11—FOSSIL FOOTPRINTS, BAROPUS HAINESI

Type.—Catalogue number 16553, Geological Museum, Ohio State University. A slab 7½ feet long by 4 feet wide, with a consecutive series of eighteen footprints.

Type locality.—Ohio, Morgan County, Center Township, section 8, southeast quarter. Three-fourths mile northeast of Hackney Store.

Type horizon.—Pennsylvanian system, Monongahela formation, just beneath the Benwood limestone member.

The slab shows a series of nine double tracks, each with a print of a forefoot (manus) and hindfoot (pes) with the toe-prints of a hindfoot track overlapping slightly the rear of a forefoot track. The tracks are shown as the imprints and consist chiefly of the prints of the ends of the toes (plate 11). The front row of prints was made by the toes of the manus and the rear row by the toes of the pes. A broad, shallow imprint of the heel of the pes is also shown in each track. The rock in which the tracks are preserved is a firm, relatively pure quartz sandstone. The sand on which the animal walked must have been rather compact, so that the sole of the foot was impressed only slightly. However, as the foot left the track the pressure placed on the toes impressed these more deeply into the sand.

Description.—Fourteen strides are shown on the slab. They range from 20¼ inches to 22 inches and average about 21¼ inches (540 millimeters). The width of the trackway from the center of a track on one side to a corresponding position on the other side is about 10 inches (250 millimeters). The ratio of width of trackway to length of stride is as

1 to 2.1. The double tracks of the right and left sides are alternate in position. The manus and pes are tetradactyl and it is probably digit V that is missing.

Manus.—Tetradactyl, plantigrade. Length, about 3½ inches (90 millimeters); spread of toes, about 5 inches (125 millimeters); general shape, semicircular, broad and short, being much shorter than the pes. Sole broadly rounded behind, with lateral edges continued as outer edges of the limiting digits. Sole and posterior parts of the digits only faintly impressed. Digits about 1 inch long. Toe-prints prominent, the second and third deeply impressed, the first and fourth less deep, but definite in most cases. The manus was toed-in toward the center line of the trackway at an angle of 30 to 40 degrees, so that the outer, or fourth, toe-print is commonly farthest forward.

Pes.—Tetradactyl, plantigrade. Length, 6¾ inches (170 millimeters); width at rear, about 2 inches, broadening forward to about 4½ inches at base of digits. Heel-print elliptical, about 4 inches by 3 inches, in posterior part of the track. Front part of the sole and posterior parts of the digits faintly or not at all impressed. Digits short, about 1 inch long. Toe-prints prominent, tranversely elliptical or circular, size and depth varying with degree of impression, up to 1 inch across in the greater dimension, up to half inch in depth; forward slopes steeper. The first and second toe-prints are the largest and deepest. The third or the second digit extends farthest forward. The fourth digit is shorter than the third and its toe-print is faintest of all. Spread of toes from center of first to center of fourth is very uniform, ranging from 5 inches to 5¼ inches, with an average for eight tracks of 5⅛ inches. No trace of claws.

Another slab (number 16554, O. S. U.) from the same locality shows two forefoot and two hindfoot tracks in obverse. The tracks are sufficiently like those of the large slab to show conclusively that they belong to the same species, but the hindfoot tracks are 3 inches back of the short forefoot tracks and the hindfoot track is also turned in slightly toward the line of trackway, but to a much less degree than the forefoot track. In the two ravines which constitute the type locality several other loose slabs were seen showing in obverse one or more, more or less complete tracks. In so far as preserved, they all appeared to belong to the same type as here described.

This species is assigned to the genus *Baropus*, which was established by Professor Marsh in 1894 by the description of *Baropus lentus* from the Coal Measures of Kansas.[3] *Baropus lentus* Marsh has four digits on

[3] O. C. Marsh: Amer. Jour. Sci., Ser. 3, vol. 48, 1894, p. 83, pl. 2, fig. 5.

manus and pes and the pes overlaps slightly or comes near to the track of the manus. Our form differs from *Baropus lentus* most prominently in the much shorter manus, in the more toed-in position of the manus, and in the shorter fourth digit of the pes, which in *Baropus lentus* is the longest; also, both the forefoot and hindfoot tracks of *Baropus lentus* have a projection of the inner edge just back of the first digit, which is not present in our species. The genus name *Baropus,* meaning heavy foot, suggests a deeply impressed track for the entire foot, which is true of *Baropus lentus,* for which Professor Marsh made the generic name. The type slab of *Baropus hainesi* (number 16553) does not show deeply impressed tracks, but it is assigned to the genus *Baropus* in spite of this fact, with the belief that a firm surface of compact sand supported the weight of the animal, so that it did not sink deeply into the sediments. Where the surface consisted of mud, as in slab number 16554 and other specimens seen in the field, the tracks are more deeply impressed and better fulfill the characteristic indicated by the generic name.

The species name of *Baropus hainesi,* here assigned, is in honor of Mr. E. R. Haines, who found the slab on his farm and recognized the marks as fossil footprints, and through whose interest and generosity the slab has come to have a place in a geological museum.

Anomœichnus, new Genus

GENERIC CHARACTERISTICS

Quadruped with plantigrade feet. Manus and pes pentadactyl. Digits of the manus short, those of the pes long. Claws on at least the pes.

Anomœichnus ohioensis, new Species

PLATE 12—FOSSIL FOOTPRINTS, ANOMŒICHNUS OHIOENSIS

Type.—Catalogue number 15329, Geological Museum, Ohio State University. A slab 5½ feet long and 2 feet wide, showing a consecutive series of sixteen footprints in obverse, equally divided between the four feet.

Type locality.—Ohio, Perry County, near New Straitsville.

Type horizon.—Pennsylvanian system, Allegheny formation, from the shales above the Middle Kittanning coal.

In the series of tracks on either side there are two types which alternate, and must therefore represent the manus and pes (plate 12). The pes came down at almost exactly the middle of the stride-interval of the manus, so that the tracks are evenly spaced and those of the right and left sides are opposite. The short-toed track is interpreted as the

forefoot track and the long-toed track as the hindfoot track. In support of this interpretation it may be noted that the three slabs under consideration, each showing a different species, all have two types of tracks which alternate, and must represent fore- and hindfeet. On each slab one type is smaller, has shorter or more slender toe-prints, and is turned in farther toward the center line of the trackway. In one of the species one type of track partly overlaps the other type, and it is the smaller, shorter-toed, toed-in type that is overlapped, and was therefore made first, and is therefore the track of the forefoot. In the other species, where there is no overlapping, the smaller, shorter-toed, toed-in type is also considered to be the forefoot track.

The tracks are shown in obverse, being the filling of the imprints, and are therefore shown as elevations on the slab. Some of the elevations are partly missing, having been broken off in the imprints when the obverse and reverse slabs were separated, but the outline of the broken part shows in most of these cases the outline of the track. In interpreting the plates of these obverse slabs it is necessary to reverse right and left.

Description.—Stride, about 17 inches; width of trackway from the center of a track on one side to a corresponding position on the other side, about 10 inches; width of trackway to length of stride as 1 to 1.7. Manus and pes pentadactyl and plantigrade. The tracks of the manus of one side opposite the tracks of the pes of the other side.

Manus.—Pentadactyl, plantigrade. Length, about 4½ inches (115 millimeters); greatest width, about 4½ inches. Sole imprint prominent, about 3½ inches long, 3¾ inches wide in the anterior part and rounded posteriorly. Digits very short and broad and represented in most of the tracks by short projections of the sole about three-fourths inch long and three-fourths inch broad at the base. Digits I to IV are evenly spaced along the anterior edge of the foot; digit V is located on the outer edge, about 1 inch back of the base of digit IV. No suggestion of claws. The manus is toed-in, so that the inner edge of the foot is directed inward at 40 degrees with respect to the line of trackway, which passes over digit III instead of digit II, as is true of the pes.

Pes.—Pentadactyl, plantigrade. Length, about 6 inches (150 millimeters); spread of toes, about 7 inches (175 millimeters). Sole prominent and continuous with bases of the digits. Length of sole, about 3½ inches; width just posterior to base of digit V, about 4½ inches; sole rounded posteriorly. The deepest part of the track was along a diagonal axis extending from the posterior outer corner to the anterior inner part, at the base of digits I and II. Digits long and of moderate width.

The average of six to eight readings gave the following:

Digit I—length, 1½ inches; width, 1 inch; directed inward at about 40 degrees.

Digit II—length, 2 inches; width, 1 inch; directed inward at about 10 degrees.

Digit III—length, 2½ inches; width ¾ inch; directed outward at about 15 degrees.

Digit IV—length, 2½ inches; width, ⅝ inch; directed outward at about 35 degrees.

Digit V—length, 2½ inches; width, ½ inch; directed outward at about 60 degrees.

Digit I is the shortest, and there is an increase in length from I to III. Digits III, IV, and V are about the same length. The second or third toe extends farthest forward. Digit I is the broadest, and they decrease outward, IV and V being the most slender. Several of the tracks show phalangeal pads. These are most characteristic of the terminal segments of digits II, III, and IV, but in some cases show for the second or third segments from the ends. Faint impressions, which are interpreted to represent claws, are present in one or two cases at the ends of digits I, II, III, and IV.

There is an interesting difference between the hindfeet tracks of opposite sides. The digits of the right pes (left side of figure) radiate outward and are approximately straight. This is true also of digits I, II, and III of the left pes (right side of figure), but digits IV and V of this foot curve outward and backward and are much less deeply impressed than the corresponding digits of the right pes. The angle of divergence of digits I and V of the right pes is about 85 degrees, while the corresponding angle for the left pes is about 100 degrees. That part of the sole near the base of digits IV and V of the left pes is also less deeply impressed than for the right pes. It is apparent that this outer part of the left pes was injured and that the digits do not have their normal position.

This form is especially characterized by the short digits of the manus and by the notable difference of the tracks of the manus and pes. This difference is so notable that some may question whether the complete manus is recorded. The slab (plate 12) shows, in obverse, four tracks of the right manus and four tracks of the left manus. The track impressions of both manus and pes were about half an inch deep and they record equally well the soles of the manus and pes and should have recorded the complete digits of the manus as definitely as those of the pes. The tracks are so uniform that one must conclude that they show

the correct form of the manus. In recognition of this difference of manus and pes, it seems best to establish a new genus for this form, and the generic name *Anomœichnus,* here given, is in allusion to the difference between the two tracks. To this the specific name *ohioensis* is joined, making the name *Anomœichnus ohioensis.*

Ancylopus, new Genus

GENERIC CHARACTERS

Quadruped with plantigrade, large-soled feet. Manus pentadactyl, digit V located on outer edge of manus. Pes tetradactyl, digit I being missing. Digit V is broadest, well set off from the others, located on the outer edge of the foot, directed outward and with the end curved backward, giving a hooklike form.

Ancylopus ortoni, new Species

PLATE 13—FOSSIL FOOTPRINTS, ANCYLOPUS ORTONI

Type.—Catalogue number 15330; Geological Museum, Ohio State University. A slab 5 feet long by 3 feet wide, showing by footprints, in obverse, the courses of two animals lengthwise of the slab. One course is a consecutive series of twelve footprints, the other of thirteen footprints.

Type locality.—Ohio, Perry County, near New Straitsville.

Type horizon.—Pennsylvanian system, Allegheny formation, from the shales above the Middle Kittanning coal.

Two types of tracks were made by this animal, and in each series or line these types alternate and must represent the manus and pes (plate 13). One type shows five narrow digits of medium length, the other type shows four digits which are broader and longer. The first type is toed-in at an angle of 30 to 40 degrees, the second type is directed almost forward in the line of trackway. The shorter toed, toed-in type, is interpreted as that of the manus. The forefoot of this animal, therefore, had five digits and the hindfoot had only four digits. This is unusual, to have more digits on the forefoot than on the hindfoot, but it is believed that the more toed-in position of one foot and the more slender digits are distinctive forefoot characteristics. The pes came down near the center of a stride-interval of the manus, so that the tracks of the right and left sides are approximately opposite and of different kind.

There is some variation in details and some of the tracks are incomplete, but on the whole they are rather notably uniform and fit into one or the other type, in accordance with their position. The tracks are shown in obverse, being the fillings of the imprints, and are therefore

shown as elevations on the slab and in reversed position as to right and left. The more diagonal course across the slab was made first, as is shown by the fact that one of the tracks of this course is partly concealed by having one of the tracks of the second course on top of it. The animal that made the more diagonal course was somewhat smaller.

Description.—Stride, about 20 inches (510 millimeters); width of trackway, about 11 inches (280 millimeters); width of trackway to length of stride as 1 to 1.8. Manus pentadactyl. Pes tetradactyl. Manus and pes plantigrade. Tracks of the manus of one side approximately opposite the tracks of the pes of the other side.

Manus.—Pentadactyl, plantigrade. Length, about 5 inches (125 millimeters). Spread of toes, about 4¼ inches (110 millimeters). Sole prominent, about 4 inches long by 3 inches wide, and impressed deeper on the inner side. Digits very slender, 1 to 1½ inches long, except digit V, which is somewhat shorter. Digits I to IV are evenly spaced around the anterior part of the foot; digit V is on outer side of the foot, about 1 inch back of the base of digit IV.

Pes.—Tetradactyl, plantigrade. Length, about 5½ inches (140 millimeters). Spread of toes, about 5 inches. Sole prominent and continuous with the bases of the digits. Length of sole, about 4 inches; width, about 3¼ inches. The deeper part of the imprint was on the inner side, with a depth of about half inch. There is no conclusive evidence as to whether it is digit I or V that is missing, but it is interpreted that it is digit I and the others are numbered accordingly. Digit II is shortest, about 1 inch long, and curves outward. Digit III is about 1½ inches long and curves outward slightly. Digits II and III are directed almost forward and are about 1½ inches distant at their ends. Digit IV is 2 to 2½ inches long and curves outward. Its end is about 2¼ inches from the end of III. Digit V is about 2 inches long and broadest of all. It is located on the outer side of the foot and directed outward, and in most of the tracks it curves strongly outward and backward, giving it a hooklike form and placing its terminus about 3 inches from the terminus of IV. This thumblike digit on the outer side of the foot has been recognized in several Pennsylvanian footprints, and is a hindfoot characteristic, thus confirming in this case the interpretation made above as to which track represents the manus and which the pes.

The digits probably had webs between their bases, especially in the manus. In those tracks where two adjoining digits are especially distant there is a definite, transverse, interdigital margin to the track, well forward, as if the web was drawn taut, while in those tracks where two adjoining digits are especially close the interdigital reentrant is deeper

and more angular as if the web, being loose, allowed the mud to rise against it between the digits. Claws were not recognized in these tracks, but toe trails are present in several cases, as shown on plate 13.

As noted above, the condition of five digits in the manus with only four in the pes is unusual, the larger number commonly being in the pes. However, at least three late Paleozoic species of different genera with this arrangement of digits have been described. These are *Allopus littoralis* Marsh, from the Coal Measures of Kansas;[4] *Magapezia pineoi* Matthew, from the Lower Carboniferous of Nova Scotia,[5] and *Agostopus matheri* Gilmore, from the Permian of Arizona.[6] Our form resembles *Magapezia pineoi* in the general form of the pes and especially in the divergent position of the outer digit, but the tracks are twice as large. The tracks of the manus of the two forms are quite different in general shape and proportions and those of our form have shorter and narrower digits. *Magapezia pineoi* has a peculiar manus in the notable development and divergent position of digits I and II. The differences are too great to permit of our form being placed in the genus *Magapezia*. With *Allopus littoralis* our form corresponds in the general size of the tracks and in the length of stride. However, our form has a relatively longer track, the digits are narrower, longer, and differently arranged, and whereas *Allopus littoralis* brought the pes down on the track of the manus, the tracks of our form are evenly spaced. Furthermore, Dr. Gilmore has recently added to the genus *Allopus* a species, *Allopus arizonae*,[7] which has "apparently five toes" in the pes and an undetermined number in the manus. If this species stands as assigned, five digits in the manus and four in the pes is not a generic characteristic of *Allopus*, and in that case our form is not sufficiently related to *Allopus littoralis* to be placed in the same genus. It is very different from *Agostopus matheri*. It seems necessary, therefore, to assign our form to a new genus and species. The genus name *Ancylopus* is in allusion to the hooklike form of digit V. The species name *ortoni* is given in honor of Dr. Edward Orton, who collected the slab and placed it in the Geological Museum.

Kind and Size of the Animals

The ratio of the width of trackway to length of stride is for *Baropus hainesi* 1 : 2.1, for *Anomœichnus ohioensis* 1 : 1.7, for *Ancylopus ortoni*

[4] O. C. Marsh: Amer. Jour. Sci., Ser. 3, vol. 48, 1894, p. 83, pl. 2, figs. 4, 4*a*.

[5] G. F. Matthew: Proc. and Trans., Royal Soc. Canada, sec. 4, 1904, pp. 102-104, pl. 2, figs. 4*a*, 4*b*, pl. 6, fig. 6.

[6] C. W. Gilmore: Smithsonian Miscellaneous Collections, vol. 77, no. 9, 1926, pp. 23-25, pl. 10 and text fig. 16.

[7] C. W. Gilmore: Smithsonian Miscellaneous Collections, vol. 77, no. 9, 1926, pp. 29-31, pl. 11, fig. 2 and text fig. 19.

1 : 1.8. These are all relatively broad trackways and indicate broad-bodied animals. Their legs were probably short, and yet long enough to carry the body and the tail entirely free from the ground. They were, therefore, much more distinctly walking animals than are the alligators of the present. In the case of *Baropus hainesi* a hindfoot track commonly overlaps slightly a forefoot track, while for *Anomœichnus ohioensis* and *Ancylopus ortoni* a hindfoot came down at or near the middle of the stride-interval of a forefoot. The fact that the body did not drag may be taken as evidence that it was of moderate length between fore and hind legs, and therefore that any particular hindfoot track was made next after the forefoot track immediately in front of it. The absence of tail trace may be taken to indicate that the tail was of moderate or short length. That their tread was heavy and their movements slow is indicated by their plantigrade feet with relatively large soles. They were most probably amphibians of the stegocephalian type.

One might wish to speculate from these tracks concerning the size and proportions of the animals that made them, but for this, very little data exists concerning these relations in similar present-day animals. Writing concerning *Leptophractus obsoletus,* Moodie says: "The species was about as large as an adult Florida alligator, and probably exceeded or at least equaled in size any of the Carboniferous Amphibia." [8] The creatures that made the tracks here described were probably as large as Leptophractus. It is believed that amphibians that had strides of about 20 inches, as was true of *Baropus hainesi* and *Ancylopus ortoni,* must have been at least 6 feet and probably 8 feet in total length; and, considering the width of the trackways and the large plantigrade feet, suggesting massive proportions for the animals, it is believed that they must have weighed at least 400 pounds.

[8] Roy Lee Moodie: Carnegie Institution of Washington, Pub. 238, 1916, p. 167.

EXPLANATION OF PLATES

PLATE 11.—*Fossil footprints, Baropus hainesi*

About one-twelfth natural size.

FIGURE 1.—*Baropus hainesi*, new species. Type, number 16553, Geological Museum, Ohio State University. Rock slab 7½ feet long, showing a series of nine double tracks. The front (upper) row of toeprints of each track represents the manus. The rear row represents the pes. The heel of the pes is shown in most cases.

FIGURE 2.—Diagram of the slab shown in figure 1. The cross-lines are 3 inches apart.

PLATE 12.—*Fossil footprints, Anomœichnus ohioensis*

About one-eleventh natural size.

FIGURE 1.—*Anomœichnus ohioensis*, new genus and species. Type, number 15329, Geological Museum, Ohio State University. Rock slab 5½ feet long, showing in relief (obverse slab) a consecutive series of sixteen tracks. The tracks showing short digits represent the manus, those showing long digits represent the pes.

FIGURE 2.—Diagram of the slab shown in figure 1. The cross-lines are 3 inches apart. Note the more divergent position of digits IV and V of the left pes (right side of figure), apparently due to injury. Prints of claws show for some of the digits.

PLATE 13.—*Fossil footprints, Ancylopus ortoni*

About one-fourteenth natural size.

FIGURE 1.—*Ancylopus ortoni*, new genus and species. Type, number 15330, Geological Museum, Ohio State University. Rock slab 5 feet long, showing in relief (obverse slab) the courses of two animals across the slab from base of view upward. One course is a consecutive series of twelve tracks, the other of thirteen tracks.

FIGURE 2.—Diagram of the slab shown in figure 1. The cross-lines are 3 inches apart. The tracks of one course are shaded to distinguish the two courses. The course shown by the shaded tracks was made first. The pentadactyl tracks are interpreted as those of the manus, the tetradactyl tracks as those of the pes. Note the large outer, hooklike digit of the pes.

FIGURE 1

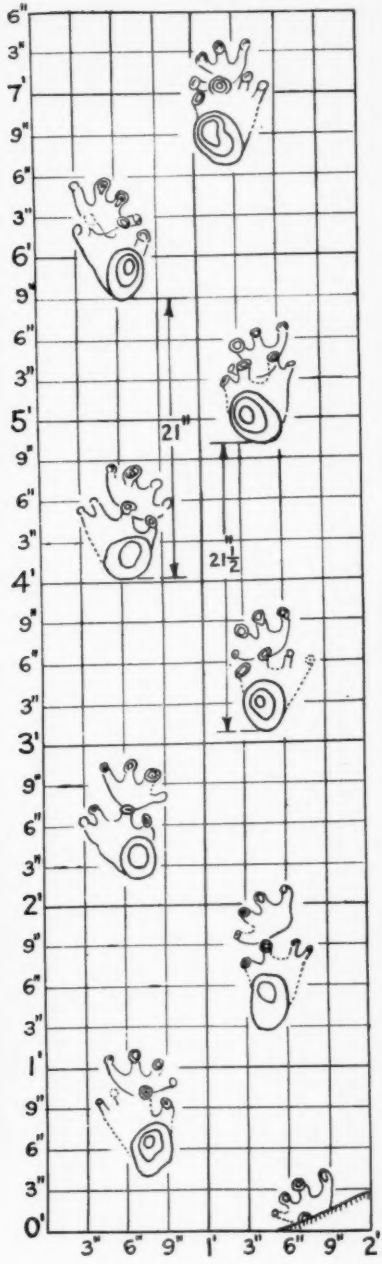

FIGURE 2

FOSSIL FOOTPRINTS, BAROPUS HAINESI

About one-twelfth natural size.

FIGURE 1

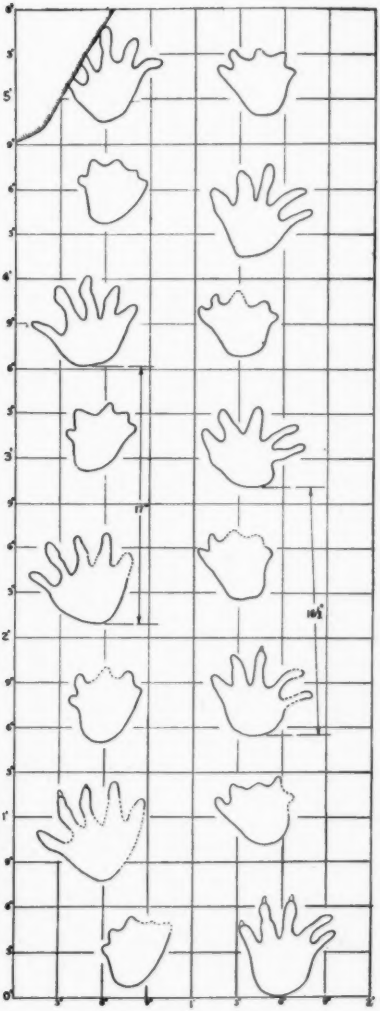

FIGURE 2

FOSSIL FOOTPRINTS, ANOMOEICHNUS OHIOENSIS

About one-eleventh natural size.

FIGURE 1

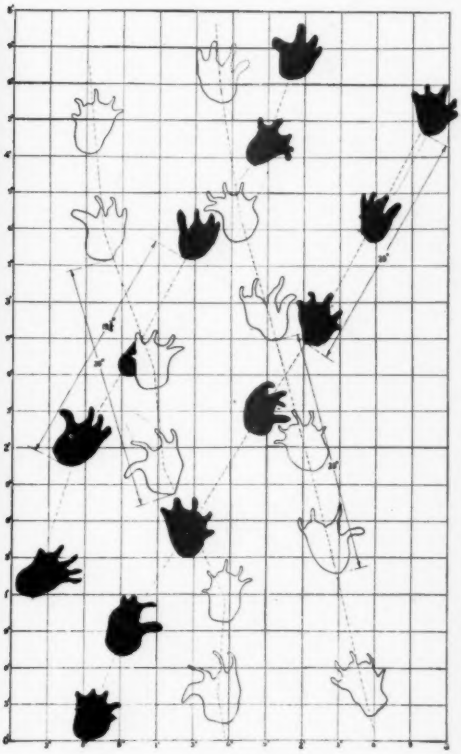

FIGURE 2

FOSSIL FOOTPRINTS, ANCYLOPUS ORTONI

About one-fourteenth natural size.

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POCONO STRATIGRAPHY IN THE BROADTOP BASIN OF PENNSYLVANIA[1]

BY DAVID B. REGER [2]

(*Presented by title before the Society December 29, 1926*)

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WORK OF THE SECOND GEOLOGICAL SURVEY OF PENNSYLVANIA

The Pocono Series of the Mississippian period entirely surrounds the Broadtop Basin of Huntingdon, Fulton, and Bedford counties of Pennsylvania. The best opportunities for its study are afforded by the gaps in Terrace Mountain northwest of the basin and just southeast of the Raystown Branch of the Juniata River near Saxton, Riddlesburg, and Hopewell, where the exposures are almost as perfect as could be desired; and in Sideling Hill, southeast of the basin and east of Robertsdale. Of these two regions the outcrops of Terrace Mountain are much the better. The Second Geological Survey of Pennsylvania long ago studied these terranes, the Pocono of Sideling Hill being exhibited in the well-known and much-discussed section of Ashburner,[3] and that of Terrace Mountain in the equally known and more satisfactory sections of White.[4]

[1] Manuscript received by the Secretary of the Society July 17, 1926.
[2] Published by permission of West Virginia Geological Survey.
[3] C. A. Ashburner: Report F, 1878, pp. 206-8.
[4] I. C. White: Report T3, 1885, pp. 79-81.

Stevenson[5] also studied the Pocono in Bedford and Fulton counties, but his sections give few details. Ashburner's section is composite, its focus being about the tunnel of the East Broadtop Railroad and Coal Company through Sideling Hill 3 miles northeast of Robertsdale. In Terrace Mountain Dr. White measured at one locality his "Shoup's Run Gap Section," slightly southeast of Saxton, and at another his "Riddlesburg Gap Section," on the Juniata River 1½ miles north of Riddlesburg.

Work of Reger in 1924

General statement

In the autumn of 1924 the writer visited this region in the course of an extended study of the Mississippian of the Appalachian States, inspecting the outcrops of Sideling Hill, remeasuring the sections near Saxton and Riddlesburg, and measuring a new one at Hopewell above and southwest of Riddlesburg. Lack of space forbids repetition of the sections of Ashburner and White, but those of the writer, which present certain new aspects of the Pocono, as well as giving the superjacent and subjacent formations, follow herewith:

Saxton section, Bedford County, Pennsylvania

Starting on the west side of Shoup Run, about 1½ miles southeast of Saxton, this section traverses northwestward partly along a branch of the Huntingdon and Broadtop Mountain Railroad, partly along the bluff beneath the railroad, and finally (numbers 21-24) along the eastern side of Shoup Run; dip southeast 35 degrees to 75 degrees; arrangement in descending stratigraphic order; thicknesses computed from pacing and vertical angles.

	Thickness, feet	Total feet
Mauch Chunk Series (——)		
1. Shale, red, poorly exposed	...	...
Pocono Series (1,142 feet)		
2. Sandstone, Logan (Burgoon), gray, massive, coarse, hard	240	240
3. Concealed	30	270
4. Sandstone, brown, thick-bedded, hard, with large plant fossils	30	300
5. Shale, dark, siliceous	5	305
6. Sandstone, dark gray, weathering rusty, thick-bedded, hard	100	405
7. Concealed, with pebbly boulders	165	570
8. Sandstone, greenish gray, shaly	40	610
9. Shale, brown, sandy (described as red by Dr. I. C. White)	20	630

[5] J. J. Stevenson: Report T2, 1882, pp. 69-72.

	Thickness, feet	Total feet
10. Sandstone, greenish gray, weathering rusty, with streaks of shale	40	670
11. *Shale, Riddlesburg,* blue black, siliceous, with plant fossils (*Lepidodendron gaspianum* reported by Dr. I. C. White), and with marine fossils, most abundant in lower part; *Lot 32¼* (U. S. number 3547*b*); contains *Spirorbis* sp., *Lingulidiscina newberryi, Schuchertella chemungensis, Chonetes acutiliratus* n. sp., *Camarotœchia contracta, Spirifer compositus* n. sp., *Cypricardinia consimilis.* (Identifications by Dr. George H. Girty)	95	765
12. Sandstone, greenish gray, massive	20	785
13. Shale, yellow, partly concealed	15	800
14. Sandstone, greenish gray, weathering yellowish brown	10	810
15. Shale, yellowish green	2	812
16. Sandstone, dark gray	10	822
17. Concealed	50	872
18. *Sandstone, Broad Ford,* partly reddish brown and partly yellowish green	30	902
19. Shale, yellow, sandy, with plant fossils	15	917
20. Concealed	35	952
(Thence offsetting to east side.)		
21. *Sandstone, Berea* (*Mount Pleasant?*), greenish gray, massive	190	1,142
Catskill Series (200 feet +)		
22. Concealed with red shale	55	1,197
23. Sandstone, reddish brown, cross-bedded, with some beds of red shale	145	1,342
24. Shale, red, abundant	...	....

RIDDLESBURG SECTION, BEDFORD COUNTY, PENNSYLVANIA

Starting on the Huntingdon and Broadtop Mountain Railroad, on the east side of the Raystown branch of the Juniata River, about 1½ miles north of Riddlesburg, and traversing northwestward along this railroad to the deep cut through a low ridge just east of the Marysville settlement; dip southeast 35 degrees to 45 degrees; arrangement in descending stratigraphic order; thicknesses computed from pacing and vertical angles.

Mauch Chunk Series (240 feet +)	Thickness, feet	Total feet
1. Shale, red, sandy, inert	200	200
2. Concealed across ravine	40	240

	Thickness, feet	Total feet
Pocono Series (1,043 feet)		
3. *Sandstone, Logan (Burgoon)*, gray, coarse, hard, with streaks of black, fissile, carbonaceous shale containing plant fragments	85	325
4. Concealed across ravine	60	385
5. Sandstone, gray, weathering rusty brown, thick-bedded, hard, with numerous streaks of quartz conglomerate, a few streaks of shale, and with ferruginous breccia; this also may be *Logan (Burgoon)*	220	605
6. Shale, olive green, brecciated, with a little sandstone and with plant fossil fragments	60	665
7. Sandstone, greenish gray, hard	35	700
8. Shale, olive green, sandy	15	715
9. Sandstone, green, fine-grained, shaly	20	735
10. *Shale, Riddlesburg* (type locality), greenish black, siliceous, exfoliating into pencil forms, with marine fossils in lower part (900 feet B), *Lot 322* (U. S. number 3548*a*); contains *Stenopora?* sp., *Spirorbis* sp., *Rhipidomella Huntingdonensis* n. sp., *Schuchertella chemungensis*, *Chonetes acutiliratus* n. sp., *Camarotœchia contracta*, *Spirifer compositus* n. sp., *Nucula* aff. *Houghtoni*, *Paleoneilo concentrica*, *Cypricardinia concentrica*, *Glossites?* sp., *Pleurotomaria* aff. *Hickmanensis*. (Identifications by Dr. George H. Girty)	75	810
11. Sandstone, greenish gray, shaly	15	825
12. Shale, red and variegated, very sandy	30	855
13. Sandstone, greenish gray, fine-grained	25	880
14. *Shale, Broad Ford Sandstone* horizon?, red, with chunks of soft, greenish gray sandstone	150	1,030
15. Sandstone, green, shaly, with plant fragments	15	1,045
16. Sandstone and red shale, interlaminated	35	1,080
17. Fireclay shale, gray	5	1,085
18. Sandstone, greenish gray	5	1,090
19. Shale, yellow	3	1,093
20. Shale, red, with red sandstone	30	1,123
21. *Sandstone, Berea (Mount Pleasant?)*, greenish gray, cross-bedded, medium hard, ripple-marked at top, with several streaks of limestone breccia (effervescent), a streak or two of red shale, and with a few plant fossils	160	1,283
Catskill Series (335 feet +)		
22. Shale, red, with red sandstone, partly concealed	245	1,528
23. Sandstone, reddish brown	30	1,558
24. Shale, red, with streaks of red sandstone	40	1,598
25. Sandstone, red	15	1,613

	Thickness, feet	Total feet
26. *Shale, Sarton* (type locality), green, well exposed on north side of deep cut, with numerous plant fossils (900 feet B), *Lot 323;* contains *Archæopteris* and considered as upper Catskill by Dr. David White; specific determinations not yet made	5	1,618

HOPEWELL SECTION, BEDFORD COUNTY, PENNSYLVANIA

Starting on the east side of Sandy Run 0.7 mile southeast of Hopewell, the Hopewell Section traverses northwestward along a branch of the Huntingdon and Broadtop Mountain Railroad to Hopewell Station; thence offsetting southwestward, along the strike, across Juniata River, and thence northwestward along the west sides of Juniata River and Yellow Creek to a point 0.3 mile northwest of Hopewell; dip southeast 30 degrees to 50 degrees; arrangement in descending stratigraphic order; thicknesses computed or estimated from pacing and vertical angles.

Pottsville Series (162 feet +)	Thickness, feet	Total feet
1. Coal opening, not examined	..	..
2. Sandstone, white, massive, hard, coarse	50	50
3. Concealed	20	70
4. Sandstone, white, massive, hard, coarse	50	120
5. Concealed	10	130
6. Sandstone, much broken and shaly	30	160
7. *Coal*	2	162
Mauch Chunk Series (1,525 feet)		
8. Shale, black, *Ralston Iron Ore*, weathering into pencil forms, with numerous nuggets of iron ore; one small impression looks like a marine fossil? or a plant root?	25	187
9. Sandstone, gray, hard	25	212
10. Concealed; contains red shale and red sandstone, with a little limestone breccia westward along Juniata River	685	897
11. Shale, red	485	1,382
12. Concealed, with red shale	175	1,557
13. Sandstone, gray, thick-bedded, coarse, hard	30	1,587
14. Shale, red	100	1,687
(Thence offsetting across Juniata River, along strike.)		
Pocono Series (1,150 feet)		
15. *Sandstone, Logan (Burgoon)*, gray, tinged with red, massive	50	1,737
16. *Coal*, prospect; abandoned; little coal on dump and not much reported	..	1,737
17. Concealed, with sandy shale	75	1,812
18. Sandstone, gray, coarse, hard	50	1,862
19. Concealed	25	1,887

	Thickness, feet	Total feet
20. Sandstone, reddish brown, thick-bedded	100	1,987
21. Shale, sandy, party concealed	20	2,007
22. Sandstone, greenish gray, thick-bedded, with a few streaks of shale	125	2,132
23. Shale, sandy and red	10	2,142
24. Sandstone, greenish gray, weathering brown	10	2,152
25. Shale, red	5	2,157
26. Sandstone, shaly	5	2,162
27. Shale, red, with a little sandstone	30	2,192
28. Sandstone, shaly	20	2,212
29. Shale, yellow, sandy, with plant fossils	10	2,222
30. *Shale, Riddlesburg*, blue black, sandy, weathering into pencil forms, with marine fossils; brachiopods	75	2,297
31. Sandstone, brown, shaly	15	2,312
32. Shale, yellow, sandy	5	2,317
33. *Sandstone, Broad Ford?*, greenish gray, weathering rusty brown, with streaks of shale and breccia, and with numerous plant fossils; outcrops at highway bridge across Juniata	100	2,417
34. Sandstone, greenish gray	10	2,427
35. Concealed, with green sandstone	400	2,827
Catskill Series (10 feet +)		
36. Sandstone, reddish brown	10	2,837
37. Shales, red, abundant, not measured	..	....

SIDELING HILL SECTION

At the locality of the Sideling Hill Section of Ashburner the writer did not remeasure the deposits, but at the southeastern end of the tunnel, about 3½ miles northeast of Robertsdale, a fossil collection was made from the shales which outcrop in the cut immediately outside the portal, these beds being the same as numbers 123 and 124 of the Ashburner Section, previously cited, and being evidently the Riddlesburg shale. Identifications by Dr. George H. Girty are as follows:

Fossil Lot 325 (U. S. number 5,438)

Lingulidiscina newberryi	*Leda* aff. *spatulata*
Schuchertella chemungensis	*Grammysia?* sp.
Chonetes acutiliratus n. sp.	*Cypricardinia consimilis*
Camarotœchia contracta	Ostracod
Paleoneilo concentrica	

Comparison of Sections

To those who are familiar with the reports of the Second Geological Survey it is apparent that the sections of White and Reger at Saxton

and Riddlesburg and that of Reger at Hopewell are all in practical agreement as to total thicknesses and other major features, while that of Ashburner in Sideling Hill differs widely both as to thickness, stratigraphic aspect, and marine fauna. Briefly summarized, the thicknesses of the Pocono are obtained as follows by the authors named:

	Ashburner. Feet	White. Feet	Reger. Feet
Sideling Hill	2,133	....	....
Shoups Run (Saxton)	....	1,130	1,142
Riddlesburg	....	1,102	1,043
Hopewell	....	....	1,150

In Sideling Hill, Ashburner's thickness of 2,133 feet includes a group of 19 thin and lenticular streaks of coal occupying 313 feet in the upper half of the series and being exposed in the railroad tunnel. These he calls the "New River Coal Series," the assumption being quite erroneous, but being attributed by Dr. White[6] to Dr. J. P. Lesley, who was then State Geologist of Pennsylvania. Attention is further called by Dr. White[7] to the fact that the combined thickness of the Pocono and subjacent Catskill is almost the same in Terrace Mountain as in Sideling Hill, indicating that different interpretations of the Pocono-Catskill contact may be partly responsible for the discrepancies in Pocono thickness.

In the Sideling Hill Section Ashburner reports *Cypricardinia* and *Orthis* in green shale at the eastern end of the tunnel, coming 427 feet below the coal group, or 1,251 feet below the top of the Pocono. At Riddlesburg Dr. White found *Spirifer* and *Rhynchonella* in black shale coming 609 feet below the top of the Pocono, the coal group being almost totally absent at this locality and elsewhere in Terrace Mountain. He also found an abundant fauna in the same black shale on Shoup Run (near Saxton), but assigned no generic names. Geologists who have studied these recorded sections without actual inspection of the region have naturally assumed that the fossils of Sideling Hill belong at a different stratigraphic horizon from those in Terrace Mountain. This view, however, now appears quite contrary to fact. At Sideling Hill the upper portion of the Pocono west of the tunnel is almost totally concealed; Ashburner[8] himself states that he studied the upper 580 feet in Ground Hog and Plank Cabin valleys and he gives no details of this portion of the series. This lack of detail, as compared to an otherwise

[6] See republication of Ashburner's section by G. P. Grimsley, in Jefferson, Berkeley, and Morgan County Report of West Virginia Geological Survey, 1916, p. 159.
[7] Report T3, pp. 83-5.
[8] Report F, p. 209.

painstaking section, indicates quite plainly that no good exposures existed and that the thickness of 580 feet was merely assumed. There could easily be an error of 200 or 300 feet. Within the tunnel itself Ashburner plainly records a stratigraphic thickness of 763 feet, but at the same time he shows a dip of only about 33 degrees on his cross-sections and a tunnel length of about 800 feet on this topographic map, this length being reported as only 600 feet by present employees of the railroad. On the basis of an 800-foot length the thickness of the tunnel beds could be only 436 feet, and on the basis of 600 feet, which is apparently the actual length, they could be only 334 feet thick. It is evident that at least 400 feet, and probably more, must be subtracted from the thickness of the tunnel beds.

According to his section, it is 1,451 feet from the top of the Pocono to the top of the fossiliferous green shale at the southeast end of the tunnel; but if 400 feet of excess thickness for beds inside the tunnel and 200 feet of excess thickness in estimated exposures northwest of the tunnel, or 600 feet in all, be subtracted, this interval from the top of the Pocono to the top of the fossils becomes only 851 feet, as compared to 670 feet at Saxton, 495 feet at Riddlesburg, and 535 feet at Hopewell. In all probability a more drastic subtraction should be made from the Sideling Hill Section, so that this true interval is hardly more than 700 feet. This would leave 1,433 feet as the total for the Pocono; but there is much doubt about the lower portion, since Ashburner records 440 feet of partly concealed beds at the base without finding a definite contact plane. As White infers, this assemblage might easily belong in the Catskill.

In addition to these important stratigraphic corrections, a further fact of much significance is afforded just east of the tunnel. Ashburner reports *Cypricardinia* and *Orthis* in 5 feet of green shale "at the east end of Sideling Hill tunnel." If he had dug carefully in the cut outside the tunnel, in the 30 feet of immediately subjacent blue black shale, he would have found almost precisely the same fauna as occurs in the Shoup Run Gap near Saxton, as is above displayed.

It is thus apparent that the thickness of the Pocono in Sideling Hill does not differ greatly from that in Terrace Mountain, that the fossil horizons found by Ashburner and White are one and the same, and that the only essential difference is the presence of a coal group in the Sideling Hill tunnel. The tunnel itself was examined several times by the writer with the aid of a track-walker's torch, but it is now so black with train smoke that few, if any, of the thin streaks of coal may now be found. Taking it for granted that they are present, however, their

occurrence in a mountain that is 10 miles nearer the old shoreline is not surprising, since the same conditions are practically duplicated in the same series farther southwest in both West Virginia and Virginia.

New Formations

The writer has herewith assigned the name of *Riddlesburg shale* to the faunal zone above mentioned, its stratigraphic position, lithologic features, and fauna being carefully recorded in both the Riddlesburg and Saxton sections above published and also more briefly noted in the Hopewell Section. Farther northeast the same peculiar lithology, apparently without marine fossils, but in several cases with rather abundant plant fossils, is visible in the same relative stratigraphic position in the gaps of Susquehanna River between Harrisburg and Millersburg, in the gap of the Schuylkill below Pottsville, and in the gap of the Lehigh opposite Mauch Chunk. Farther west its marine facies appears to be represented in a fossiliferous shale containing a slightly different fauna, on the northwestern slope of the Chestnut Ridge anticline, where it is cut by the Conemaugh River, in Westmoreland County. What seems to be the same black shale occurs also in Alleghany County, Virginia, along the Chesapeake and Ohio Railway, between Alleghany Station and Lewis tunnel, *Centronella julia* being the only fossil noted.

In the Saxton, Riddlesburg, and Hopewell sections there is also noted the horizon of the *Broad Ford sandstone,* occurring either as a massive bed or as a succession of sandy beds with interstratified red shale. This sandstone has recently been named by Reger[9] from the spectacular reef it makes at the gap of Laurel Creek of Holston River, at the line between Smyth and Tazewell counties, Virginia, just north of Broad Ford village, where it contains *Syringothyris* and other marine fossils, in addition to the fucoid, or annelid? *Taonurus cauda galli.* It is traceable for many hundreds of miles along the Appalachians in Tennessee, Virginia, West Virginia, and Pennsylvania, generally by its reddish brown color, which is distinctive from nearly all other standstone beds of the Pocono, and also in part by its marine fauna. In southern West Virginia, however, *Taonurus* disappears north of Elkins, Randolph County, and in central Pennsylvania the marine fauna also vanishes; but the reddish brown color reappears from place to place, and the bed is especially prominent in the ridge east of Gouldsboro Lake in the Pocono Mountains, near the northern line of Monroe County, Pennsylvania. This sand-

[9] Mercer, Monroe, and Summers Report, West Virginia Geological Survey, 1926, pp. 520-525; see, also, Economic Geology, vol. 20, no. 8, December, 1925, pp. 777-779.

stone is the backbone of the whole series and definitely links together the Grainger, Price, and Pocono formations.

In the Sideling Hill, Huntingdon County, number 122 of the section of Ashburner[10] shows 165 feet of "hard, coarse-grained, reddish gray sandstone, alternating with soft, yellow, sandy shale," coming immediately below the fossiliferous Riddlesburg shale and apparently representing the Broad Ford horizon.

The base of the Pocono in the Broadtop Basin, as in nearly all other regions where the Pocono Series is found, appears to be made by the Berea sandstone, as noted both in the Saxton and Riddlesburg sections. Although seldom containing marine fossils, except in northwestern Pennsylvania, this ledge may be identified over wide areas by its prevailing lithology and by its relationship to the immediately superjacent black and fissile Sunbury shale, which can be traced from Delaware County, Ohio, southeastward across the Appalachian geosyncline, into southern West Virginia, through the medium of many hundreds of oil-well records. When it reappears at outcrop in southern West Virginia the Sunbury not only preserves its lithology, but also its marine fauna—*Lingula melie* and *Orbiculoidea* (*Lingulidiscina*) *herzeri*—as well. These characteristics of the Sunbury persist across West Virginia and far into Pennsylvania, and separate quite effectively the Berea sandstone from the Broad Ford. The three members—Berea, Sunbury, and Broad Ford—comprise an inescapable stratigraphic assemblage that defines the basal portion of the Pocono and marks its essential difference from the underlying Catskill Series of the Devonian, in which no similar succession may be found.

The Berea sandstone appears, without much doubt, to correlate with the Mount Pleasant conglomerate of White,[11] as first described by him in Wayne County, Pennsylvania, in 1881, and as therein assigned to a transitional, or sub-Pocono, group, but definitely regarded as the basal member of the true Pocono by the same author[12] in 1882. East of the Broadtop Basin in Pennsylvania the correlation of the Berea (Mount Pleasant) sandstone must be accomplished by stratigraphic methods alone, or by plant fossils, since no marine faunas have been found in the Pocono of that region.

In the Riddlesburg Section as above given, there is noted in the upper portion of the Catskill Series of the Devonian a green shale carrying plant fossils and herein designated as *Saxton shale*, its interval from the

[10] Report F, p. 208.
[11] Report G5, p. 58.
[12] Report G6, pp. 89-91.

base of the Berea sandstone of the Pocono being 330 feet and its visible thickness 5 feet. This shale assumes an importance far beyond its apparently trivial aspect, because horizons which carry recognizable remnants of plants are exceedingly scarce in the Catskill and few of them may be traced from place to place. The Saxton shale, however, appears to be a very constant member of the upper part of the Catskill, having been recognized by the writer at such widely scattered localities as the gap of the Susquehanna River through Berry Mountain, south of Millersburg, Dauphin County, Pennsylvania; along the Lackawanna Trail, in the Pocono Mountains of Monroe County, Pennsylvania; on the western slope of the Laurel Ridge arch, where it is cut by the Conemaugh River, near the common corner of Westmoreland, Indiana, and Cambria counties, a few miles northwest of Johnstown, Pennsylvania; and on Rockwell Run south of Orleans Crossroads, Morgan County, West Virginia; and at numerous points in Randolph County, West Virginia. At these and other localities its interval below the base of the Berea sandstone, or the apparent base of the Pocono, varies from 100 to 800 feet, depending much on the local development of the Catskill, the interval being usually greater in regions where the Catskill is thick. Collections made from this shale by the writer are now in the hands of Dr. David White for study, his preliminary verdict being contained in the following brief paragraph:[13]

"Did I not write you that the material you sent me was undoubtedly Catskill, and probably upper Catskill, the fossils being fragments of *Archæopteris*?"

In his study of the Catskill of northeastern Pennsylvania Dr. I. C. White[14] reports *Archæopteris jacksoni* in his Montrose red shale and in his underlying Paupack sandstone, coming roughly 600 to 800 feet below the base of the Mount Pleasant conglomerate or base of the Pocono, most of the localities noted being along the eastern end of the Pocono Mountains. There is ground for belief that the Saxton shale is correlative with one of these earlier named members, but unfortunately the writer has had no opportunity to visit the Pocono region since this interesting question became apparent.

Catskill-Pocono Boundary

The Saxton shale is herein introduced and briefly discussed because of its evident value in the determination of the Catskill-Pocono, and there-

[13] Letter of December 2, 1924.
[14] Report G5, 1881, p. 63, and Report G6, 1882, pp. 103 and 320.

fore of the Devonian-Mississippian, boundary. If it can be definitely traced throughout the outcrop of its horizon in Pennsylvania, Maryland, West Virginia, and northern Virginia, as appears probable from the ease with which it was recognized by the writer at most localities visited after its discovery, late in the fall of 1924, its decisively Catskill flora should eliminate many errors in regions where there is an interfingering of red and green sandstones of Catskill type with gray conglomerates having Pocono aspects.

Disconformity at Top of Pocono

The sections at Saxton, Riddlesburg, and Hopewell afford no satisfactory view of the upper boundary of the Pocono, since the limestones which separate it from the Mauch Chunk farther east in the basin are wholly absent or wholly concealed. Farther northeast, however, this boundary is exposed on Trough Creek at the northern base of Round Mountain, where the Logan (Burgoon) sandstone of the Pocono makes a massive cliff, of which 75 feet are visible above drainage, followed immediately by 50 feet of red and siliceous limestone which has been locally described as the Trough Creek limestone by White[15] without reference to its age, except that it is included under the discussion of the Mauch Chunk Series. In an earlier report Ashburner[16] handles it as a subdivision (XI*b*) of the Mauch Chunk Series, designating it as "The Mountain limestone ('Lewisburg limestone' of the Greenbrier region in Virginia; 'Saint Louis and Chester limestone' of the Mississippi Valley)." This very early correlation of Ashburner, if slightly qualified and amplified, is quite near the truth, except that no portion of the Saint Louis is present.

In following the Trough Creek limestone from Terrace Mountain southward in Trough Creek Valley, it is apparent, as already described by Ashburner and White, that there is generally a lower bed of quite siliceous limestone, usually resting on the Pocono, but infrequently separated from it by a few feet of red shale, followed above by red shale or calcareous sandstone, which is in turn followed by a second limestone of general persistence. A careful study of these limestones reveals that both are oolitic, and that the upper one contains a rather poorly preserved marine fauna, specific determinations of which are afforded in the reports of Ashburner and White, the more recent collections of the writer being still under study by Dr. Girty.

There is small doubt that the lower bed of limestone is the same as

[15] Report T3, 1885, pp. 73-6.
[16] Report F, 1878, pp. 199-202.

the Loyalhanna, or siliceous, limestone of Westmoreland, Fayette, and other counties farther west in Pennsylvania, as described in many reports and as assigned by Stevenson, Campbell, and others to the top of the Pocono Series. This view was entertained for many years, but more recently Butts[17] has correlated it with the Sainte Genevieve. There is abundant evidence in substantiation of the interpretation of Butts and little or none in favor of the earlier correlation with the Pocono. In passing southwestward across Pennsylvania the lower bench of the Trough Creek, or the Loyalhanna "Siliceous" limestone, becomes thicker, but generally remains oolitic and cross-bedded, being nearly always separated from the overlying fossiliferous limestone by a calcareous sandstone or shale. At Greer, Monongalia County, West Virginia, on the Chestnut Ridge anticline, this relationship is still apparent, but here the Loyalhanna becomes fossiliferous, containing fragments of gastropods, brachiopods, and crinoids. From this locality southwestward across West Virginia it gradually loses its siliceous character and becomes a highly marine limestone, while at the same time the calcareous sandstone or shale which separates it from the overlying fossiliferous limestone almost totally disappears. From southern West Virginia the two limestones, in close conjunction and generally without visible disconformity, can be traced across southwest Virginia into Kentucky and Tennessee, where the correlation of the lower with the Fredonia member of the Sainte Genevieve and the upper with the Gasper limestone of the Chester Series is well established. There is ample evidence for belief that the Maxville limestone of Ohio, which has been considered as Chester by some authors and as Sainte Genevieve or Fredonia by others, is the same combination of Gasper and Fredonia, without visible disconformity, just as these occur in southern West Virginia.

Returning now to the Broadtop Basin of Pennsylvania, it is the view of the writer that the lower, or siliceous, bench of the Trough Creek Limestone may be safely correlated with the Fredonia member of the Sainte Genevieve, and that the upper, or fossiliferous, bench of the Trough Creek is a remnant of the Gasper. These combined beds are a constituent part of the Greenbrier Series of southern West Virginia and Virginia, where they are separated from the overlying Mauch Chunk Series by another heavy limestone which is almost, if not totally, absent from Pennsylvania, and where they are separated from the underlying Pocono by 1,200 to 1,800 feet of older limestones of Greenbrier age, and by 400 to 700 feet of still older Maccrady beds, which are made up of red shales,

[17] Charles Butts: Mississippian Series of Eastern Kentucky. Kentucky Geol. Sur., 1922, pp. 155-6.

limestone, and sandstones of probable Warsaw or Keokuk age. There is thus apparent in the Broadtop Basin of Pennsylvania a great disconformity of about 2,500 feet between the lower bench of the Trough Creek limestone and the upper member of the Pocono Series, although there is so little local evidence of its occurrence either in the Broadtop Basin or elsewhere in Pennsylvania, that many able geologists have not only missed it entirely, but have even assigned this limestone to the much older Pocono Series.

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PRE-CAMBRIAN AND PALEOZOIC GEOLOGY OF FORTUNE BAY, NEWFOUNDLAND[1]

BY NELSON C. DALE

(*Presented by title before the Society December 29, 1925*)

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INTRODUCTION

In visiting the localities herein described the writer's purpose was to investigate the general geology of the area as well as to seek a possible recurrence of the manganese deposits found along the shores of Conception and Trinity bays (Dale, 2). Limitation of time, inaccessibility of many of the rock exposures, as well as uncertainty of transportation made it possible only to collect data bearing on the general geology of

[1] Manuscript received by the Secretary of the Society November 23, 1926.

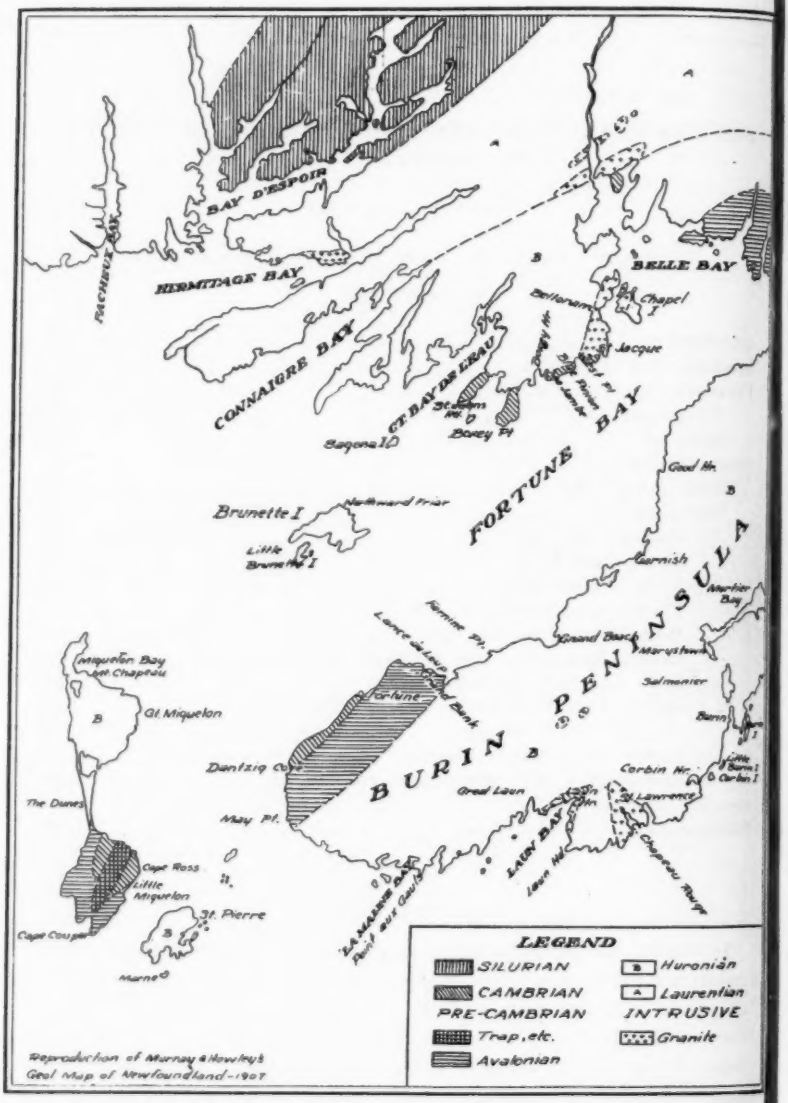


FIGURE 1.—*General areal geological Map of Part of the south Coast of Newfoundland*

Fortune Bay. The object, therefore, in presenting these notes is to have the results of the work recorded.

The writer expresses his grateful acknowledgments to the Department of Geology of Princeton University for its courtesy and assistance in

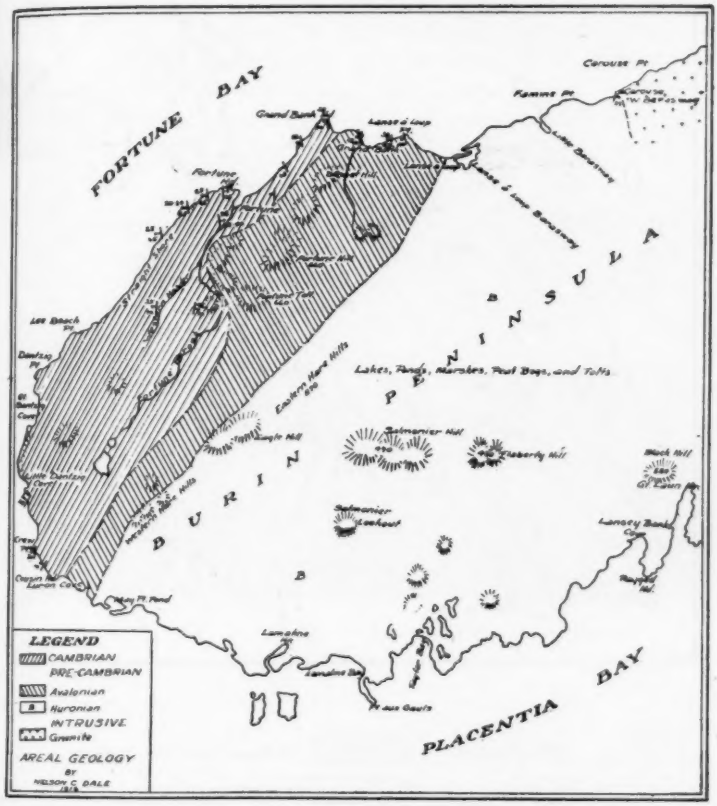


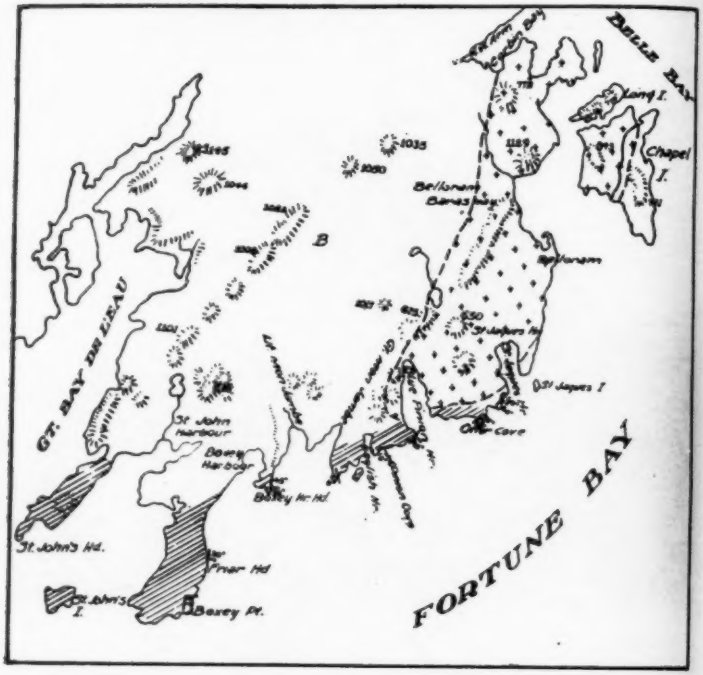
FIGURE 2.—*Areal geological Map of southern Part of Burin Peninsula, Newfoundland*

furthering this expedition, and to Dr. B. F. Howell, of the same department, who kindly identified the fossils.

GEOGRAPHY AND LOCATION

This area includes the tip of Burin Peninsula and that part of the west shore of Fortune Bay lying between Saint Jacques and Saint Johns

Head. Fortune Bay is located approximately between longitude 55 and 57 east and latitude 46 and 48 degrees north. Burin Peninsula is the most conspicuous feature of the south coast of Newfoundland and is nearly 75 miles long and 10 to 25 miles wide. Separating Fortune Bay


GT. BAY DE L'EAU
FORTUNE BAY
St. John harbour
Long I.
Chapel I.
St. John's Hd.
Bay de Loup
Bay de Grave
Bay de Grave Pen.
Bay de Grave Hr.
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PHYSIOGRAPHY

TOPOGRAPHY

Fortune Bay, like Conception and Trinity bays and other bays of Newfoundland, appears to have been formed by the partial submergence of a plateau, as shown by the indented configuration of its shoreline, the distribution of the principal islands, Great and Little Miquelon, Saint Pierre, and the Brunettes, and the dismembered character of the streams, especially those at the north end of Fortune Bay.

Although not quite as rugged as the shores of a typical Norwegian fiord, parts of Fortune Bay and other Newfoundland bays have much

FIGURE 4.—*West Shore of Fortune Bay, near Belloram, Newfoundland*
Photograph by N. C. Dale

in common with them. The canal-like straightness, depth, and general U and trough shape of many of the smaller bays, such as Saint Jacques Harbor, which is just west of Saint Jacques Island (figure 3), Long Harbor, Hermitage Bay, as well as the larger ones, which are really the embayed or drowned portions of river valleys, suggest the work of the glacier. The complex rectangular system of the Norwegian fiords seems to be lacking in most of the Newfoundland bays, although present in Mortier Bay, on the east side of Placentia Bay, the west shore of Trinity Bay, and much of Notre Dame and Bonavista bays.

Into Notre Dame and Fortune bays there enter streams whose lower reaches have the appearance of fiords. In other respects these bays have

the appearance of the Ria type of shoreline, partaking of the embayed plateau or mountain type, due to the dismembered or drowned features of the lower reaches of the streams. Doubtless continential glaciation and marine erosion have modified the original outline and shape of these bays.

Except for a morainal deposit of from 50 to 100 feet in thickness, capping the rocks between Dantzig Point and Fortune Head, extending for a few miles northward on Burin Peninsula, most of the shoreline of Fortune Bay is of a rugged character. Between Dantzig Point and Lunon Point there are precipitous cliffs averaging 400 feet in height. Between Cousin Head and Dantzig the shoreline is typified by a marine cut ter-

FIGURE 5.—*North Shore of Saint Jacques Harbor, Newfoundland*
Photograph by N. C. Dale

race in process of development, on which are many low, sharp-crested hogbacks which extend for a quarter of a mile or less from the precipitous cliffs seaward. Figures 4 and 5 illustrate the type of shoreline found on the west shore of Fortune Bay. Sudden heights of 775 and 1,129 feet and the pink color of pre-Cambrian granite cliffs of Belloram and Chapel Island are particularly striking features of the west coast of Fortune Bay.

Another noticeable characteristic of the west shoreline of this bay is the manner in which the strike of the bedding plane and joints control the lineaments of the shoreline. This feature is much more pronounced on the west shore of Fortune Bay than on the eastern, particularly in connection with the major divisional planes of the pre-Cambrian and

Cambrian rocks which occur between Saint Jacques Harbor and English Harbor, as well as those of the harbors of Little Mon Jambe and Great Mon Jambe. The north 10 degrees east joint plane is the cliff forming shoreline of the harbor of Saint Jacques and of others.

Differential weathering and marine erosion of numerous basaltic dikes account for the rectangular indentations and promontories.

The topography inland from the shores of Burin Peninsula is that of a low plateau nearly or completely covered with peat-bogs and numerous lakes and ponds, the monotony of which is broken only here and there by a low tolt or hill. This plateau has been brought to its present low relief by peneplanation and uplift, the isolated tolts and necks representing monadnocks.

DRAINAGE

Fortune Brook, with its main tributary, Western Leader, is the only water system of this part of the peninsula, draining the plateau and debauching northward into the barasway at Fortune.

Inland from the cliff dominating the shoreline, and outside of the barrens or plateau, and even on the slopes of the hills and tolts, abounds the ever-present sphagnum moss, holding the moisture that supplies the numerous lakes and ponds.

From the top of Fortune Tolt or from any other similar rise can be seen many ponds and lakes in various stages of extinction, brought about through the process of filling by the growth of sphagnum moss and its development into peat.

General Geology

GENERAL STATEMENT

The rocks of the Fortune Bay area are of late pre-Cambrian and Lower and Middle Cambrian, the pre-Cambrian rocks occupying by far the greater part of the area, the Cambrian being represented only in a few fringes located partly on the toe of Burin Peninsula, on the east shore of Fortune Bay, and partly between Saint Jacques Harbor (figures 1 and 2) and Saint Johns Head, on the west shore (figure 3). On figure 2 the writer has tried to include some of the more important areal changes as well as those affecting the legend. These changes may be better appreciated by comparing figure 2 with figure 1, the latter being a reproduction of a part of James P. Howley's 1907 Geological Map of Newfoundland. No parts of the areas marked (B) Huronian were investigated except those indicated in the text. Furthermore, it was not possible to visit the French possessions of Great and Little Miquelon.

The contact between the Cambrian and pre-Cambrian on the east shore lies about halfway between Grand Bank and Grand Bank Head, in the bay head beach called Admiral Cove (figure 2) and is in all probability an unconformable one. The series at the west end of the beach is different from that at the east end, the former consisting of metamorphosed clastics with worm trails (?) of Lower Cambrian age, while the latter consists of reddish, purplish, and greenish felsitic sills and dikes intruding agglomerates and volcanic conglomerates, all characteristic members of the Avalonian (Avondale) system.

In structure also the two series are different, the Cambrian series at the west end striking north 38 degrees east and dipping 70 degrees north, while the pre-Cambrian series has an approximate north 28 degrees east strike and 30 degrees south dip.

In attempting to correlate these two great series with those about Conception and Trinity bays, only the larger structural relationships and lithology can be of any service with the pre-Cambrian rocks, while with the Cambrian paleontology has been used as the safest criterion.

PRE-CAMBRIAN

General statement.—The later pre-Cambrian succession in Newfoundland, as worked out by Murray, Howley, and Walcott, is as follows:

		Feet
Randon	Sandstone, quartzitic sandstone, and sandy slates	1,000
	Red conglomerate	500
Signal Hill	Dark red sandstone	1,320
	Greenish or gray fine-grained sandstone	1,300
Momable slates	Dark-brown or blackish slates	2,000
Torbay slates	Green, purple, pinkish, and red slates	2,200
Conception slates	Greenish slates.	
Lower Huronian	Mixed igneous and aqueous deposits in a highly metamorphosed condition.	

The Fortune Bay pre-Cambrian, on the east side of the bay, was studied from the east side of Admiral Cove as far northeast as Carouse West Barasway and inland in the vicinity of Fortune Tolt. The rocks all bear a most striking resemblance to Buddington's Avondale volcanics (Buddington, 1), consisting for the most part of fine and coarse-grained reddish volcanic conglomerates and sandstones, metamorphosed pyroclastics, rhyolitic and basaltic sheets, and dikes with occasional lavas.

All stratified members of this series show the effects of earth movements, with dips of 30 degrees to 50 degrees west, and strike inland between north 15 degrees east and north 60 degrees east. In the Grand

Bank Series as well as in the Lanse à Loup Series, some minor faulting has taken place.

The whole series, from the youngest at Grand Bank eastward, consists of coarse- and fine-grained conglomerates and sandstones with intruded sills of red and green porphyritic and felsitic rhyolite accompanied by green and red pyroclastics. The conglomerates, as a rule, consist of red and black felsite and quartz pebbles, some of the pebbles measuring as high as one foot in diameter.

Grand Bank Series.—The Grand Bank series is in part as follows:

a. Green rhyolite porphyry.
b. Banded red felsite and green porphyritic rhyolite.
c. Green rhyolite lithic and crystal tuff.
d. Banded red felsite and green porphyritic rhyolite.
e. Dark reddish felsitic rhyolite with porphyritic rhyolite characterized by chloritic spots.
f. Green rhyolite porphyry.
g. Dark-red calcareous tuff with dark red bands.
h. Purplish lithic and crystal rhyolite tuff.
i. Green rhyolite porphyry.
j. Reddish rhyolite.

This sequence of rocks, less than 100 feet in thickness, is quite representative of the intrusive and finer-grained pyroclastic members of the Grand Bank Series.

In the coarser-grained pyroclastics, which largely consist of acidic and basic felsites and porphyries of reddish and purplish color, the groundmass and the breccia fragments vary greatly in those in which the groundmass predominates compared to those in which the fragments predominate. Volcanic breccias are distinguished from volcanic conglomerates by degree of angularity of the shape of the fragments, the more rounded fragments, peculiar to the conglomerates, being due to water action and attrition prior to incorporation by the lava. In the conglomerate and sandstone series associated with the true pyroclastics, it is possible to distinguish the two types by the shape of the pebbles of the conglomerate and the greater preponderance of sedimentary material in the former.

Associated with this series may be found some of the more active centers of pre-Cambrian vulcanism, known in Newfoundland as tolts, of which there are several in the region under consideration. A. F. Buddington has described those about Conception Bay (Buddington, 1). Fortune Tolt, for the location of which the reader is referred to figure 2, is a volcanic neck, 860 feet above sealevel, with a conspicuous summit of 50

feet above the base and 75 feet in width, consisting largely of red and gray porphyritic rhyolites which weather pink and white respectively. On the north side, near the base of the hill, is a large patch of coarse red and gray porphyry breccia, indicating, no doubt, the place of eruption or at least the explosive part of it. Not far from the breccia are interbedded flows of red porphyritic rhyolite as well as red and gray felsitic rhyolite (figure 6). The weathering of these flows is shown in the kaolinization of the feldspar.

In cross-section, Fortune Tolt (figure 6) appears to consist of red and gray porphyritic rhyolite, weathering to pink and white, in contact, near the base of the hill, with an area of coarse breccia composed of fragments of red and gray porphyritic rhyolite. Just north of the tolt occur flows

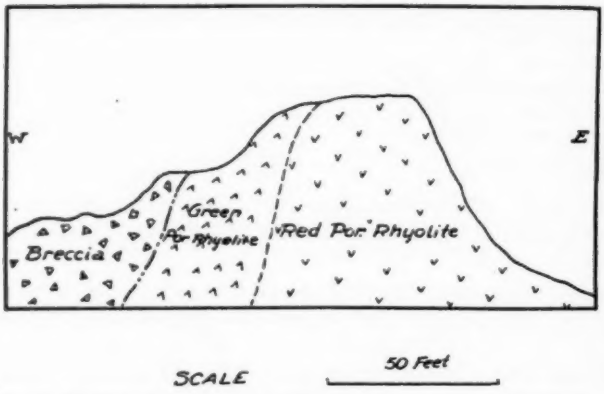

FIGURE 6.—*East-west Section of Fortune Tolt, Fortune, Newfoundland*

of interbanded white weathered, red felsite and coarse red porphyritic rhyolite, cut by a north 40 degrees east coarse red porphyritic felsitic rhyolite dike.

Under the microscope the white weathered, gray porphyritic rhyolite, which in the hand specimen appeared to be almost perlitic in structure, is hardly a glass and consists of a microfelsitic groundmass of quartz, orthoclase, pyroxene, muscovite, and phenocrysts of orthoclase, albite, and quartz. Scarce grains of pyrite and segregations of magnetite are present. This type approaches most closely to a glassy texture of any of the Fortune Bay igneous rocks investigated. Secondary products, noticeably kaolin, chlorite, and limonite, in descending order of importance, are especially common, particularly kaolin, which apparently gives rise to an unglazed porcelain-like coating of the weathered rhyolite.

The rocks of Fortune Hill (figure 2) are not unlike those of Fortune Tolt, consisting largely of greenish gray porphyritic and felsitic rhyolite flows, dikes, and segregations, with conspicuous breccia areas. The writer believes that Fortune Tolt, Fortune Hill, and Bennet Hill are all parts of the same eruption because they are all along a line which is parallel with the strike of the series (figure 2).

Lanse à Loup Series.—To the east of the Grand Bank Series, in the vicinity of Lanse à Loup, occurs a succession of flows, intrusives, and pyroclastics of a decided basic character. In general they consist of breccia flows, dark reddish and grayish porphyritic and amygdaloidal basalts, accompanied by varicolored coarse- and fine-grained pyroclastics. Many of the latter are well stratified. In the series are found coarse and fine agglomerates and conglomerates with red and gray felsite and porphyry fragments and pebbles measuring from 6 to 24 inches in diameter, many of which weather a lighter color than the groundmass. From a study of the breccia fragments and the intrusive nature of the basalt, it would not be unreasonable to assume that the Lanse à Loup Series was later in age than the Grand Bank rocks, which are more acid in composition and fragments of which are found in the basalt flows and breccias.

An interesting but very confused set of conditions is found in the Lanse à Loup Series, a part of which follows:

a. Two hundred and fifty feet of volcanic conglomerates cut by a dike of dark-gray amygdaloidal porphyritic basalt with amygdales of epidote.

b. Four hundred to five hundred feet of volcanic conglomerates and breccias, with a circular zone of coarse mottled flow basalt which is noticeably bleached near the breccia contact. In these mottled areas there are lighter and darker colored parts which show sinuous boundaries. Some of the darker areas, measuring 15 to 20 feet, show color gradations into green vertically, but a sharp contact horizontally between the darker or red and green. The lighter-colored rock is essentially a breccia consisting largely of feldspar and fragments of dark-red porphyry. A quartz vein cuts this series.

c. Salmon pink and green felsites.

d. Red agglomerate.

e. Greenish gray porphyry.

f. Reddish porphyritic amygdaloidal epidotic basalt.

g. Grayish green porphyritic basalt with epidote along joint planes.

The noticeable absence of straight and continuous contacts and the presence of vertical color gradations and flow structures indicate an intermingling of acidic and basic flows with differentiation tendencies.

In both the Grand Bank and Lanse à Loup Series of igneous rocks

the pyroclastics are found intimately associated with volcanic conglomerates. In both, highly colored and strongly bedded crystal and lithic tuffs are found associated with sills of red and green felsitic rhyolite, all striking northeast and dipping to the northwest.

Famine Point-Carouse W. Barasway Series.—Outcropping along the shore north of Lanse à Loup for a considerable distance on either side of Famine Point, in what Mr. Howley has classified as Hurohian, is a low cliff of massive pink felsite porphyry consisting almost entirely of a groundmass of pink orthoclase with euhedral quartz phenocrysts. A noteworthy characteristic of this igneous body is the presence of small chloritized xenoliths.

In descending order of importance, the following minerals occur: quartz, orthoclase, kaolin, chlorite, and magnetite. The absence of noticeable ferromagnesian minerals as well as plagioclase is striking.

Approaching Carouse W. Barasway as far as the contact of the porphyry with the greenstone and pillow series, the porphyry becomes increasingly darker, assuming almost a chocolate color and at the same time showing an increase of chloritized inclusions. Associated with some of the inclusions are nests of pink amethystine fluorite indicating the presence of fluorine during the intrusion of the porphyry into the greenstone series.

This porphyry body may possibly be related or connected with the one found at Lawrence and Lance Bay across Burin Peninsula and on Placentia Bay, where Mr. Howley has described the country around Lawn as "consisting almost entirely of reddish felsite or feldspar porphyry with occasional broken and shattered masses of stratified rocks, in places about an acre in area, but more usually less in other places, in great fragments caught in and surrounded by the igneous or intrusive rocks. These stratified fragmentary patches are black slate containing numerous nodules of iron pyrites, dull white and reddish limestone, red and green slate, all of which have a primordial aspect, but are apparently destitute of fossils" (Howley, 6). In this same report mention is made of a vein of fluorspar in this same igneous body.

About a quarter of a mile west of W. Barasway is the contact of the porphyry and the greenstone-pillow lava series, the latter bearing north 40 degrees east and dipping 25 degrees to the east. With this series occur at least four pillow lavas, all considerably chloritized and epidotized.

Thin-sections of the pillow lava show it to be an amygdaloidal diabase with amygdales of hematitic calcite. Hematite pigment is found rimming the plagioclase lathes and amygdales as well as replacing them.

At this locality the pink felsite porphyry is probably intrusive into the greenstone-pillow lava series, as is indicated by the irregular contact itself as well as by the exomorphic color effect in the porphyry. It was not possible to trace the source of the xenoliths from the data collected at that point, though they were in all probability derived from that series as a result of the intrusion.

In all probability the Lanse à Loup Series and those just described are a part of the same eruption, judging from their lithology, but antedate the pink felsite porphyry.

In general the igneous rocks of the east coast of Burin Peninsula consist largely of acidic and basic felsitic and porphyritic types which were once erupted from active volcanoes or as flows, sills, or dikes and small

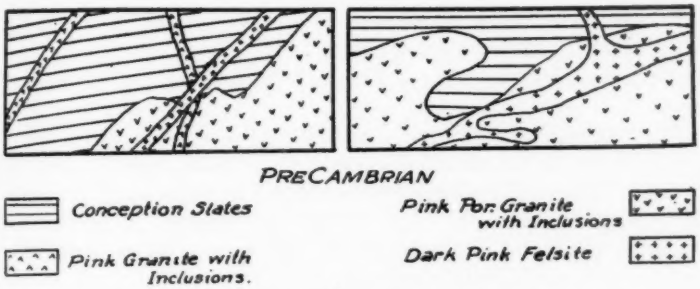

FIGURE 7.—*Pre-Cambrian igneous Contact Details*

batholiths. The acidic types are prevailingly massive, flow, and eutaxitic, while the basic rocks exhibit massive, flow, amygdaloidal, and vesicular structures. Both types have their pyroclastic phases.

In composition neither type shows any great range, the acidic being represented by the more felsitic members of the granite clan, while the basic type is represented by the more diabasic and felsitic members of the gabbro clan.

Among the basic rocks secondary products, such as epidote, calcite, and chlorite, either filling the amygdales or as surface coatings, were frequently seen. Some of the amygdaloids resemble leopardites, but are very basic, the amygdales of chlorite, calcite, and epidote accounting for the similarity in appearance.

West shore of Fortune Bay.—Some of the pre-Cambrian rocks of the west coast of Fortune Bay that were investigated occur between Belloram and English Harbor (figure 3). Some idea of the topography may be had by referring to figure 4. Just west of the entrance of Saint Jacques

Harbor Conception slates and Cambrian quartzites are intruded by three vertical dikes of pink granite porphyry, measuring 35 feet in width for two of them and 21 feet for the other. The rock of these bodies is like that of the irregular stock between Saint Jacques and Belloram and undoubtedly are apophyses from it. A very characteristic feature of the Saint Jacques Harbor porphyry is the abundance of xenoliths, the material of which resembles that of the Conception slates, which are of a dark-gray siliceous nature, and therefore suggests their source. Details of the contact may be had by referring to figure 7. Other dikes of this same nature occur along the shore to the west.

Another granite porphyry was found on the west shore of English Harbor and in contact with Carboniferous conglomerate. This rock is very different from the Belloram porphyry, consisting of a pinkish chocolate-colored felsitic groundmass, with phenocrysts of dark red orthoclase measuring up to a third of an inch in diameter, and less abundant quartz, the phenocrysts being in far greater abundance than the groundmass.

This English Harbor granite porphyry can be seen to good advantage on Red Head, an island off the mouth of English Harbor, where the Carboniferous red sedimentary series is tilted at an angle of 60 degrees to the west and intruded with red granite porphyry sills. Angular fragments of chlorite, as a record of the mechanics of intrusion, are very abundant in the Red Head porphyry.

On Boxey Harbor Head (figure 3) are several large dikes of this same porphyry—one 200 feet wide, another 20 feet wide, and still another of unknown width—all conforming with the strike of the sedimentary series, but dipping from 30 degrees to 55 degrees to the east, while the associated strata dip only 30 degrees.

There are numerous dikes and sills of felsitic and porphyritic diabase cutting the conglomerate and sandstone series between English Harbor and Boxey Point Peninsula. Chasms indenting the shoreline show the destructive effects of marine erosion on the dikes which once occupied the place where the chasms are.

Though no contact relations between the English Harbor red porphyry and the diabases were observed, it is believed by the writer that they are later in origin if the chloritized xenoliths may be interpreted as of diabase source.

General summary of the pre-Cambrian.—Though no definite intrusive relations have been established between the Famine Point and the Lanse à Loup Series, the writer believes that such relations could be found, and

if so, that they would belong to the Avondale volcanics, along with the earlier more acid rocks of the Grand Bank Series, which, in their type locality, consist of rhyolite and plagioclase basalt flows, with corresponding breccias, crystal, lithic, and vitric tuffs, volcanic dust beds, and average tuffs, together with volcanic conglomerates, sandstones, and slates (Buddington, 1). The pink quartz porphyry of Famine Point and of Belloram, undoubtedly of the same body, represent a later period of igneous activity, possibly that of the Penokeean revolution, at the close of the pre-Cambrian time.

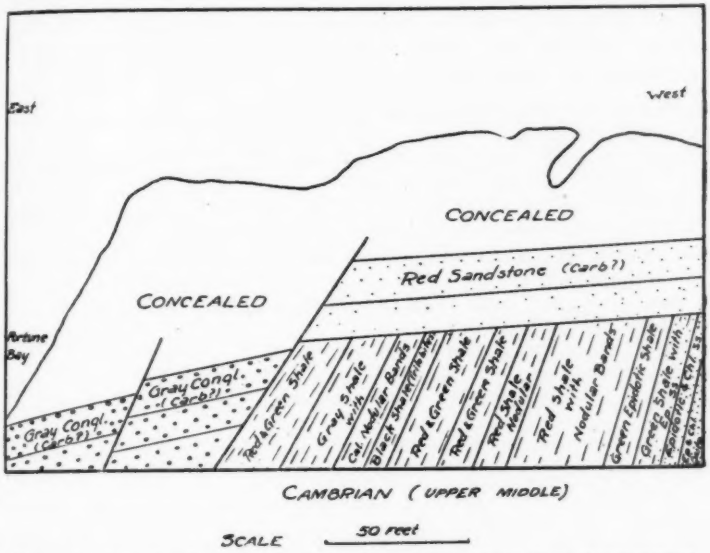

FIGURE 8.—*Cambrian-Carboniferous (?) Contact at West Pinion Cove, Newfoundland*

If the interpretation of the rock succession at the west end of West Pinion Cove given below is correct, namely, that the coarser clastics, consisting of coarse conglomerates and sandstones, essentially arkoses, are of Carboniferous age, lying unconformably on the Cambrian, both of which series have been faulted and intruded by movements and intrusions of post-Carboniferous age, then in all probability these coarse red porphyries and basalts are of much later age than the Belloram and Famine Point intrusives, possibly of Mesozoic time. The late Mr. Howley considered these coarse sediments as belonging to the Carboniferous age.

So far as could be ascertained from the field, the stratified rocks of the

pre-Cambrian, consisting largely of dark-gray banded quartzites, light-gray cross-bedded quartzose sandstone, brown weathering greenish gray slates, and banded gray slates, follow the shoreline from the south head of Saint Jacques Harbor to the west head of West Pinion Cove. Their structural relations with their igneous intrusions have already been referred to on pages 418 and 419.

CAMBRIAN AND LATER SEDIMENTS

West Pinion Cove to Boxey Point Section.—At West Pinion Cove, in apparent conformity with this series, is one of green and red nodular slates followed by green and black fossiliferous shale with coprolitic beds of Upper Middle Cambrian age. Figure 8 shows the succession and the outstanding structural relations. In detail this section is as follows:

10. Red and green slate with contorted and crushed cleavage bands.
9. Covered by talus.
8. Gray shale with bands of red calcareous nodules carrying Hyolithes and trilobite fragments, 30 feet.
7. Dark fossiliferous shale with *Paradoxides (davidis)*, Agnostus, and coprolites in the form of phosphatic and pyritic nodules.
6. Red and green shale with nodular bands, with Linguella and trilobite fragments.
5. Red shale with nodular bands and calcite vein.
4. Green slate with epidote areas.
3. Green and red shale with epidotic sandy beds.
2. Epidotic and chloritic sandstone.
1. Quartzite with cavities lined with epidote and chlorite.

Both the Cambrian and pre-Cambrian strike about north 65 to 75 degrees east and dip 50 degrees to the south.

The younger and overlying sedimentary rocks, separated from the Cambrian by a marked unconformity, represent the Carboniferous, according to an oral communication from the late Mr. Howley. This upper series consists essentially of dark-red and gray sandstones and conglomerate, the dark clastics lying immediately over the Cambrian, while the gray-colored strata represent the uppermost part of the series.

In certain respects these rocks found between West Pinion Cove and Boxey Point Peninsula resemble the basal conglomerates of the Carboniferous found near Bathurst, New Brunswick (Dawson, 3); but, taken together with their many intrusives, they resemble the Devonian of Nova Scotia (Dawson, 4). "It is also to be observed that in the Acadian Province, in passing downward from the Carboniferous to the Devonian, we constantly find unconformability, and that there is ample evidence that the great masses and dikes of intrusive granite which in

Nova Scotia penetrate all the rocks older than the Carboniferous belong to the close of the Devonian period." Not until more intensive field work has been done in this region will the exact horizon for these beds be determined. The unconformable relations established at West Pinion Cove (figure 8) prove only that they are later than the Cambrian, but it is quite possible that they may be Devonian or Carboniferous in age.

The changing strikes and dips of the Devonian (?) or Carboniferous (?) rocks, as shown in figure 3, would indicate, so far as the ground covered is concerned, that the major structure is largely synclinorial, the indentations of Great Mon Jambe and Little Mon Jambe partaking of the nature of a syncline, while Boxey Harbor and Boxey Point Peninsula are part of an anticlinal limb.

The normal strike for this series, as observed at West Pinion Cove, is east to west and the dip is 10 degrees south, but there are notable variations from these, as shown in figure 3. Such variations of strike and dip were most noticeable where there were intrusions of the coarse red porphyry, which fact would indicate that these intrusions were a factor in the folding of the sediments. Brecciated porphyry at the English Harbor contact as well as at several other contacts would indicate post-intrusive movements.

Fortune Brook Section.—The Cambrian of Fortune Bay, like that of Conception and Trinity Bay, consists of a series of strata fringing parts of the shorelines of bays and peninsulas. The western fringe of the toe-part of the Burin Peninsula, as shown in figure 2, gives the largest exposure observed in the region and much larger than is indicated in figure 1, where are included rocks of both earlier and later dates. Some of the rocks occurring between Fortune and Grand Bank and mapped as Avalonian on Howley's 1907 map are found to be Cambrian.

Because of the highly metamorphosed character of much of the Cambrian of Fortune Bay, as well as the inaccessibility of many of the shoreline exposures, only a few fossiliferous localities were noted. The most important exposures were along the banks of Fortune Brook and one of its tributaries, Horse Brook, which system flows into Fortune Harbor at Fortune. About one-half a mile inland occurs the following succession, the members of which strike north 25 degrees east and dip vertically:

Fortune Brook Section

e. Bluish shale with pencil fracture.

d. Bluish limestone, 1¾ feet..... ***Hartella matthewi*** (Hartt).
Paradoxides eteminicus Matthew.

c. Dark bluish shale, 2¾ feet.....	*Hartella matthewi.* *Bailiella baileyi* (Hartt). *Paradoxides bennetti* Salter. *Paradoxides eteminicus* Matthew. *Liostracus tener* (Hartt). *Liostracus ouangondianus* (Hartt). *Acrothele matthewi.*
b. Fossiliferous nodular limestone, 1 foot.	*Eoorthis papias* (Walcott)? *Hartella matthewi* (Hartt). U. Benneti Zone. *Paradoxides davidis* Salter? *Agnostus lævigatus terranovicus matthewi.*
a. Dark-gray shale.	

In the bed of Horse Brook, a small tributary of Fortune Brook, which drains the western slope of Fortune Tolt, is a section of some 500 feet of dark-gray shales dipping 40 degrees toward the east. In the light-colored concretionary bands of the dark-gray shale *Paradoxides benneti* is found. This section probably corresponds to the lower part of the Fortune Brook Series, and both, according to Howell, are Lower Paradoxian or Lower Middle Cambrian in age.

Cousin Head-Dantzig Section.—The exposures from Cousin Head along the shore to Dantzig, on the tip of Burin Peninsula, consist of a very closely folded and somewhat locally faulted series of normal and metamorphosed sedimentary rocks, which, for the greater part, consist of red and green shales, sandstones, slates, and quartzites. Fossils were found only in certain grayish shale and nodular pinkish limestone members.

In a gray shale member of this series within a short distance from Cousin Head, *Paradoxides bennetti* and *Paradoxides eteminicus* Matthew were found and in the nodular limestone associated with dark-gray fossiliferous and red shales not far from Little Dantzig Cove *Callavia broggeri* (Walcott), *Coleoloides, Micrometra labradorica, and Hyolithids* (?) were seen. From the preponderance of red and green shales with their nodular beds, one is reminded of the Brigus and Smith Point sections, the lower parts of which, according to Howell and van Ingen (van Ingen, 9), are Lower Cambrian.

In structure the Cambrian system of Fortune Bay appears to consist of strongly folded, slightly faulted and intruded, normal and metamorphosed clastic sediments. The general structure of the system, as shown in the various exposures, is synclinorial, consisting of many minor asymetrical synclines whose axial planes have a range in strike between north

25 degrees and north 50 degrees east. The dips range from 10 degrees west on Cousin Head to nearly vertical at Grand Bank.

Stratigraphic and paleographic relationships.—One of the most significant inferences in regard to the Newfoundland Cambrian is that of its relationship with both the American and European beds, the Newfoundland Cambrian holding a large number of species common to both regions. The faunas of England, however, resemble those of Newfoundland more closely—in fact, many of them are identical—which seems to indicate that the Cambrian areas of England and Newfoundland consisted of a single life province, made up largely of shallow-water forms which migrated back and forth over the shortest route between these two regions (Howell, 5).

General Summary

1. The shorelines of Fortune Bay, for the most part, resemble the ria type, but are considerably modified by marine erosion and in all probability by continental glaciation.

2. Inland from the shores of Fortune Bay the topography is essentially that of a plateau brought to its present state of development through peneplanation. The tolts, or volcanic necks, are apparently remnants of a former peneplane before uplift effected the region.

3. The pre-Cambrian rocks found on the east shore of Fortune Bay, between Grand Banks and Famine-Carouse W. Barasway, consist for the most part of fine- and coarse-grained reddish volcanic conglomerates and sandstones, metamorphic pyroclastics, rhyolite and basalts in sheets and dikes, with occasional pillow lavas, the latter intruded by pink granite porphyry.

4. These rocks are not unlike the Avondale volcanics of the Avalonian system, and therefore later than the Huronian, the Grand Bank Series representing the youngest of the sedimentaries, while the pink porphyry of Famine Point represents the most recent of the pre-Cambrian events. On the west shore this same pink porphyry is seen intruding a still higher member of the Avalonian sedimentaries, rocks which resemble the Conception slates found near Saint Johns.

5. The Cambrian rocks now found fringing parts of the shoreline of Fortune Bay consist of fossiliferous shales, nodular limestones, sandstones, slates, and quartzites of Lower and Middle Cambrian age.

6. The Newfoundland Cambrian fauna, a shallow-water fauna in large part, holding much in common with the Cambrian of Great Britain and North America, indicates that all the faunas in the three countries belong to the same province, and that they migrated back and

forth between North America and Great Britain by way of the shortest route, through Newfoundland.

7. The red and gray sandstones and conglomerates found between West Pinion Cove and Boxey Point are undoubtedly post-Cambrian and are either Devonian or Carboniferous in age.

8. The intrusives found with these later sediments are either of Devonian or Mesozoic age.

Bibliography

1. A. F. Buddington: The pre-Cambrian rocks of southeast Newfoundland. Journal of Geology, volume XXVII, number 6, 1919.
2. N. C. Dale: The manganese deposits of southeast Newfoundland. American Philosophical Society Proceedings, volume LIV, 1915.
3. J. W. Dawson: Acadian Geology, page 227, The Carboniferous system.
4. ———: Acadian Geology, page 497, The Devonian period.
5. B. F. Howell: The Middle Cambrian beds at Manuels, Newfoundland, and their relations. American Philosophical Society, volume LI, number 1330, 1920.
6. Jas. P. Howley: Geological Survey of Newfoundland, 1881.
7. J. B. Jukes: Excursions in and about Newfoundland.
8. Alex. Murray: Geological Survey of Newfoundland, 1881.
9. Gilbert van Ingen: Table of the geological formations of the Cambrian and Ordovician systems about Conception and Trinity bays, Newfoundland, and their northwestern American and western European equivalents, 1914.

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TENTATIVE CORRELATION OF THE PERMIAN FORMATIONS OF THE SOUTHERN GREAT PLAINS[1]

BY CHARLES N. GOULD AND ROBIN WILLIS

(Presented in abstract before the Society December 28, 1926)

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INTRODUCTION

The Permian rocks of the Great Plains region of North America occupy parts of the following States: Oklahoma, Texas, New Mexico, Kansas, Colorado, Nebraska, and Wyoming. This paper is concerned only with the occurrence of the Permian in the first four States named.

The map (figure 1) shows the approximate areas occupied by these rocks. It will be noted that Permian rocks are exposed on the surface in central and southwestern Kansas, western Oklahoma, in certain parts of western Texas, and in eastern New Mexico. The Permian occurs subsurface throughout much of western Kansas, a small part of western Oklahoma, throughout practically all of the Panhandle and trans-Pecos Texas, and most of that part of New Mexico lying east of the Pecos River.

For more than fifty years geologists have studied the Permian formations exposed on the surface in these States. Of the scores of workers only a very few can be mentioned at this time. Among the principal men

[1] Manuscript received by the Secretary of the Society February 21, 1927.

who have added to our knowledge of the subject have been Cragin and Prosser in Kansas; Cummins, Gordon, and Udden in Texas; Baker and Böse in Texas and New Mexico; Lee and Girty and Darton in New

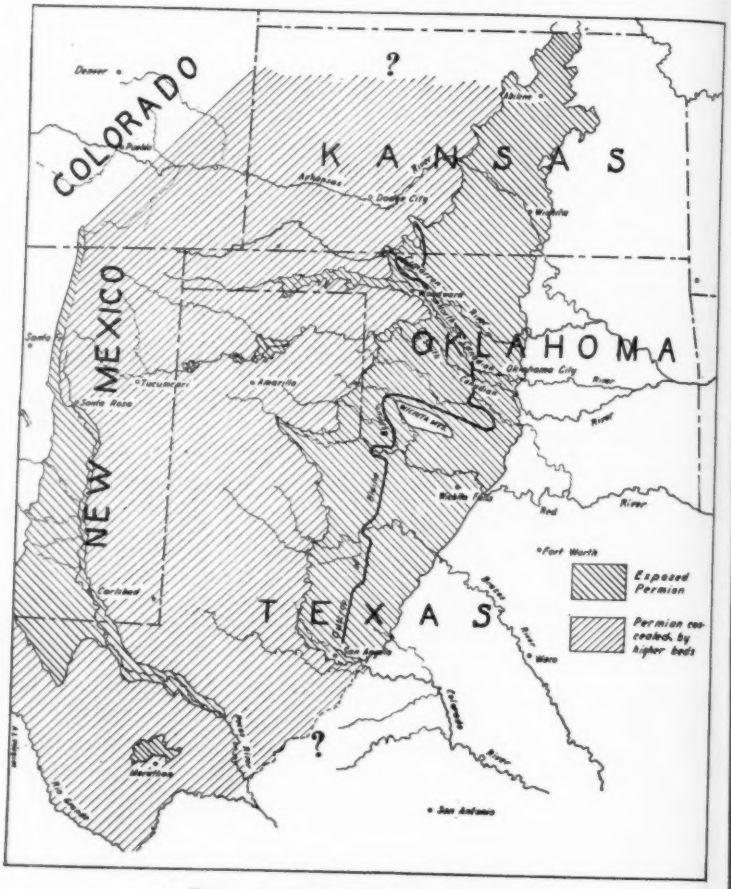

FIGURE 1.—*Map of southern Great Plains*
Showing surface and subsurface occurrence of Permian rocks.

Mexico, while Beede, who is today recognized as our best authority on the American Permian, has worked in all four States. Williston and Case have contributed largely to our knowledge of the vertebrate life of the Permian, and David White has written concerning the fossil plants.

The Problem

With a few notable exceptions, the greater part of the work of these various men has been in restricted areas. Although the surface exposures in Kansas, Oklahoma, and northern Texas are continuous, different geologic sections have been built up at various times by independent workers, and not until within the past two years have these sections been correlated.[2] The present paper deals with the correlation of these sections with the Permian section in northeastern New Mexico.

The finding of oil and gas in commercial quantities during the past few years in Permian or subjacent rocks in each of the four States named has given a tremendous impetus to geologic work in this region. Hundreds of geologists, some of them among the keenest and most capable young men in the science, are now engaged in searching for oil in these States. Hundreds of wells are being drilled for oil throughout the area. The logs of these wells are being plotted, elevations located, samples tested, heavy minerals identified, and fossils studied. The torsion balance, the seismograph, the magnetometer, and the plane-table are all being employed. All the various methods known to the geological fraternity are being used to determine both the structure and stratigraphy of the various formations. We believe that we are justified in making the statement that no other equal area of North America is today receiving such careful geologic scrutiny as is the area herewith discussed. Advantage has been taken of this wealth of information and of the interest now being manifested to attempt to correlate the various Permian beds.

Paleogeography

In order to understand the problems involved, it will be necessary to review very briefly the paleogeography of the region.

It is generally believed by students of North American paleogeography that the Permian rocks of the southern Great Plains were deposited in a retreating sea during a time of aridity.

To quote from Schuchert:[3]

"The Permian is the closing period of the Paleozoic era, and with the close of the Lower Permian all of North America was dry land. There is in our continent no record of Middle and Upper Permian times other than of erosion.

"The marine waters that laid down these deposits came from the Pacific

[2] C. N. Gould: Correlation of the Permian of Kansas, Oklahoma, and northern Texas. Bulletin of the American Association of Petroleum Geologists, volume 10, number 2, 1926, pp. 144-153.

[3] Charles Schuchert: Text book of geology. Pirrson and Schuchert. Part 2, Historical geology, second revised edition, 1924, pages 420 et seq.

across northern Mexico; they were normally marine toward the south and west, but their northern and eastern extensions spread vast sheets of red beds that have thick deposits of gypsum and salt. It was an epeiric sea surrounded by desert conditions, and the brackish-water phase, the red beds, entombed in places a wonderful series of reptiles and amphibians.

"By far the best known sequence of American Permian formations is that of Texas, where they appear to continue the Pennsylvanian strata without a marked break. In the central and northern part of the State they are of red beds phase, and as such are continued north across central Oklahoma and Kansas into eastern Nebraska. In the north these deposits are not thick and are of brackish-water origin, thickening more and more into Oklahoma and Texas, where toward the west sandstones, sandy muds, and clays are dominantly red in color and abound in vast quantities of gypsum. There is also in places considerable limestone and dolomite. . . .

"The red color and the presence of gypsum and salt are the striking phenomena of the latest Pennsylvanian and early Permian deposits of the southwestern United States."

One question which has caused much discussion is that of the origin of the sediments which made up the Permian red beds. The question has not yet been definitely settled, but as more and more evidence comes to light it appears evident that it is to the various landmasses which surrounded the retreating sea that we must look for the source of the greater part of these sediments, namely, Siouxia, the Ancestral Rocky Mountains, the Ozark Uplift, the Ouachita, Arbuckle, and Wichita Mountains, and Llanoris.

"The Permian deposits probably represent the net result of sediments carried into the southwestern retreating seas by rivers flowing from the northwest, north, northeast, east, and southeast. The matter of the quantitative value of each of these sources remains to be determined."[4]

Methods of Work

During the past two years five field conferences have been held under the auspices of the Oklahoma Geological Survey in the northern part of the region discussed in this paper, namely, southern Kansas, western Oklahoma, northwest Texas, and northeastern New Mexico. More than one hundred geologists have participated in these conferences. To the information obtained on these various conferences, supplemented by a study of the literature, have been added the findings of a number of geologists engaged in both surface and subsurface investigation throughout the region.

[4] C. N. Gould and F. E. Lewis: The Permian of western Oklahoma and the Panhandle of Texas. The Oklahoma Geological Survey, circular number 13, 1926, pp. 27-28.

In arriving at the conclusions set forth in this chart we have endeavored to use all possible available data. Fossils are usually rare in the Permian, but fossil evidence has been used whenever possible. In many instances surface outcrops have been correlated and subsurface beds have been traced by means of well logs and driller's samples. The junior author has had at his disposal the facilities and data of the geological offices and laboratories of the Marland Oil Company and wishes to acknowledge the cooperation of J. V. Howell and J. J. Maucini, of that Company. He is contributing to this paper by permission of its officials.

While it is doubtless true that new data will require us to modify certain of our present views, it is believed that the conclusions herewith set forth are in the main correct. At least these correlations represent the combined ideas of the men best qualified to express opinion as of December, 1926.

Correlation of the Permian

The correlation chart (page 438) attempts to set forth our present knowledge of the correlation of the Permian beds in the region discussed. The names in the Kansas section are largely those of Prosser and Cragin; those in Oklahoma largely those of the senior author of this paper; the Texas names are from Cummins, Udden, Böse, and others, while the New Mexico names are largely those of Girty and Lee.

The key for the correlation of the Permian of Oklahoma, Kansas, and north Texas is the Blaine gypsum—a persistent gypsiferous formation, from 100 to 600 feet in thickness, which is exposed on the surface from southwest Kansas, across western Oklahoma, and as far south as the Colorado River in Texas—a distance of 600 miles. The surface outcrop of the base of the Blaine is shown in figure 1. Below this formation, and separated from it by gypsiferous red clay shales, is a persistent sandstone formation, which in Kansas is known as the Harper, in Oklahoma as the Duncan, and in Texas as the San Angelo.

Our present practice is to correlate the Blaine with the San Andres, and the Duncan-San Angelo with the Glorieta,[5] as those latter formations are exposed along the Pecos River in northeastern New Mexico. The reasons for this correlation are shown by the cross-section obtained from a series of well logs shown in figure 2, taken across the Panhandle of Texas and supplied by the junior author.[6]

[5] The spelling of the names San Andres and Glorieta, as given here, is taken from that of the type localities, the San Andres Mountains and Glorieta Mesa, as shown on the U. S. Geological Survey's topographic map of New Mexico.

[6] The correlations shown on this section were first worked out by J. V. Howell and A. W. McCoy.

Salt Basins

One very significant fact among many that might be mentioned, which have been brought to light as the result of subsurface studies throughout the region, is the matter of the salt basins in the Permian. It has long been known that there were immense deposits of salt in the States being discussed, as set forth by a number of geologists and summarized by Darton.[7] It has usually been thought that all this salt belonged to the

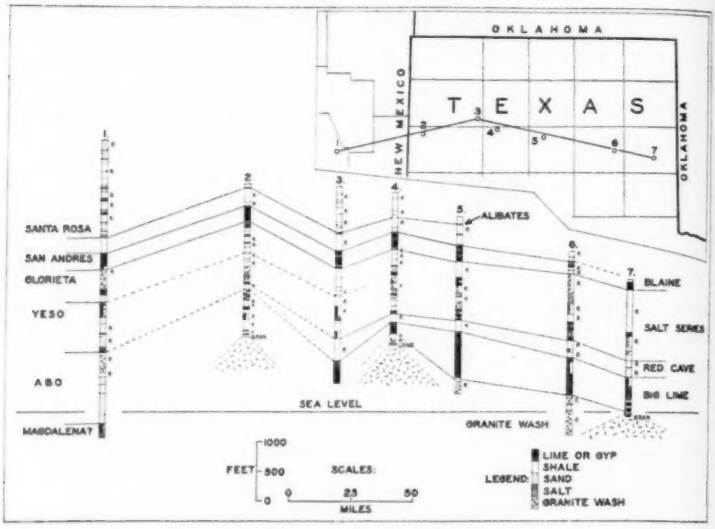

FIGURE 2.—*Cross-section of the Texas Panhandle*

1. Marland Oil Company.. Bell Ranch number 1.... San Miguel County, New Mexico.
2. Humble Oil Company.. Shelton number 1..... Oldham County, Texas.
3. Prairie Oil and Gas... Lyman and Balfour 1... Hartley County, Texas.
4. Producers and Refiners. Bivins A-2..... Potter County, Texas.
5. Humble Oil Company... Burnett number 2..... Carson County, Texas.
6. Holmes *et al*..... G. S. Morse number 2... Gray County, Texas.
7. Vaughan *et al*..... Krey number 1..... Wheeler County, Texas.

same period of deposition, but it is now known that there were three separate and distinct salt basins. The salt in southern Kansas and northern Oklahoma is believed to be of Wellington age; the salt series encountered by the drill in the Amarillo oil field of the Panhandle of Texas is of Garber-Duncan-Chickasha age, lying just below the Blaine, while the salt

[7] N. H. Darton: Permian salt deposits of south-central United States. U. S. Geol. Surv. Bull. 715, 1921, pp. 205-230.

of the southern high plains is considered to be of post-Blaine age. This condition fits in very consistently with our idea of a southwestward retreating sea.

Color Change

Another phenomenon which has already been remarked in studying the Permian is the difference in color in the different rocks. It has been said that in Kansas, Oklahoma, and northern Texas part of the Permian rocks are red and part non-red, and that the red rocks predominate. It has also been remarked that there are two kinds of Permian literature, the read and the non-read, and that the latter predominates. It is a notable fact that the Council Grove-Chase-Marion Series of Kansas, which makes up the Flint Hills, consists of shales and limestones which are mostly non-red in color. On coming south the limestones become thin and disappear, the shales change color, sandstones come in, the entire series changes to typical red beds, and the rocks are grouped under the formation name Stillwater. So in northern Texas the Albany beds which are composed of non-red shales and limestones grade north into the red beds of the Wichita. The Big Lime of the Panhandle is shown in the cross-section as grading westward into the red beds of the Abo. All of these formations lie at or near the base of the Permian. The similarity of these gradations suggests uniformity of climatic conditions and confirms the correlation of the Abo-Big Lime with the Wichita-Albany and the Stillwater-Marion-Chase-Council Grove. The comparatively limited red beds of the Abo, Wichita, and Stillwater are different in color and character from the more widespread Clear Fork, Garber, Hennessey, and Yeso red beds, suggesting different paleogeographic conditions and aiding our correlations. A marked color change is also found nearly everywhere between the Quartermaster and the overlying Triassic, though both might well be termed red beds in the general sense of the term.

In this brief paper space does not permit of the presentation of the detailed evidence for all of the correlations suggested. However, the authors hope that the general statement of them will serve a useful purpose, not only in making known available information, but also in stimulating discussion and investigation, thereby hastening the final solution of the problems involved.

CORRELATION OF THE PERMIAN FORMATIONS OF THE SOUTHERN GREAT PLAINS

Southern Kansas		Central and western Oklahoma		North central Texas		Panhandle of Texas, part subsurface	Northeast New Mexico	
PERMIAN	Big Basin	Quartermaster		DOUBLE MOUNTAIN	Quartermaster	Quartermaster	Upper red beds	
	Hackberry Day Creek Whitehorse Dog Creek	Cloud Chief Day Creek Whitehorse Dog Creek			Cloud Chief Whitehorse Dog Creek (?)	Cloud Chief Alibates Whitehorse Dog Creek (?)	Castile (upper ?)	
	Blaine	Blaine			Blaine	Blaine	CHUPADERA	San Andres
	Flower Pot Cedar Hills Salt Plains	ENID	Chickasha		Chickasha (?)	Panhandle Salt Series		Glorieta
	Upper Harper		Duncan		San Angelo			Yeso
	Lower Harper		Hennessey Garber	Clear Fork		"Red Cave"		
	Wellington (salt)		Wellington (salt)	Wichita-Albany		Panhandle Big Lime Series	Abo	
	Marion Chase Council Grove		Stillwater				Missing (?)	
PENNSYLVANIAN	Wabaunsee	Pontotoc		Cisco			Magdalena	

Compiled by Charles N. Gould and Robin Willis.

Literature

G. I. Adams: The Carboniferous and Permian age of the red beds of eastern Oklahoma from stratigraphic evidence. American Journal of Science, fourth series, volume 12, 1901, pages 383-386.

F. L. Aurin, H. G. Officer, and C. N. Gould: Subdivision of the Enid formation. Bulletin of the American Association of Petroleum Geologists, volume 10, number 8, 1926, pages 786, 799.

C. L. Baker: Origin of the Texas red beds. University of Texas Bulletin, number 29, June, 1916.

——: Contributions to the stratigraphy of eastern New Mexico. American Journal of Science, fourth series, volume 49, 1920, pages 99-126.

J. W. Beede: Relationships of the Pennsylvanian and Permian faunas of Kansas and their correlation with similar faunas of the Urals. (Abstract.) Science, new series, volume 29, April 16, 1901, pages 637, 638.

——: The bearing of the stratigraphic history and invertebrate fossils on the age of the anthracolithic rocks of Kansas and Oklahoma. Journal of Geology, volume 17, number 8, 1901, pages 710-729.

——: Invertebrate paleontology of the Upper Permian red beds of Oklahoma and the Panhandle of Texas. Kansas State University Science Bulletin, volume 4, number 3, March, 1907, pages 113-171.

——: Invertebrate faunas and correlation of some so-called Permian rocks of the Mississippi Valley, with remark on their stratigraphy. (Abstract.) Science, new series, volume 29, 1909, page 752.

——: Formations of the Marion stage of the Kansas Permian. Kansas Academy of Science Transactions, volume 22, 1909, pages 248-256.

——: The correlation of the Guadalupian and the Kansas sections. American Journal of Science, fourth series, volume 30, August, 1910, pages 131-140. (Abstract.) Science, new series, volume, 32, August 12, 1910, page 224.

——: Origin of sediments and coloring matter of the red beds of Oklahoma. Science, new series, volume 35, March 1, 1912, pages 348-350. (Abstract.) Science, new series, volume 35, February, 1912, page 311. (Abstract.) With discussion by I. C. White. Bulletin of the Geological Society of America, volume 23, number 4, December 17, 1912, pages 723-724.

——: The Neva limestone in northern Oklahoma, with remarks upon the correlation of the invertebrate fossil beds of the State. Eastern outcrop of the Permian red beds in Oklahoma, with a discussion of the lithologic and color changes. Oklahoma Geological Survey Bulletin, number 21, 1914.

——: Notes on the geology and oil possibilities of the northern Diablo Plateau in Texas. University of Texas Bulletin, number 1852, 1918.

——: Geology of Cook County, Texas. University of Texas Bulletin, number 1850, 1921.

J. W. Beede and Hedwig T. Kniker: Species of the Genus *Schwagerina* and their stratigraphic significance. University of Texas Bulletin, number 2433, September, 1924.

Compiled by Charles N. Gould and Robin Willis.

J. W. Beede and D. D. Christner: The San Angelo formation. University of Texas Bulletin, number 2607, 1926.

Emil Böse: Contribution to the knowledge of Richtofenia in the Permian of west Texas. Bulletin of the University of Texas, number 1916.

———: The Permo-Carboniferous ammonoids of the Glass Mountains, west Texas, and their stratigraphical significance. University of Texas Bulletin, number 1762, 1917.

———: On the ammonoids from the Abo sandstone of New Mexico and the age of the beds which contain them. American Journal of Science, fourth series, volume 49, 1920, pages 51-60.

E. C. Case: The red beds between Wichita Falls, Texas, and Las Vegas, New Mexico, in relation to their vertebrate fauna. Journal of Geology, volume 22, 1914, pages 243-259.

———: The Permo-Carboniferous red beds of North America and their vertebrate fauna. Carnegie Institution of Washington, Publication Number 207, 1915.

———: The environment of life in the late Paleozoic in North America; a paleogeographic study. Carnegie Institution of Washington, Publication Number 283, 1919.

F. W. Cragin: The Permian system in Kansas. Colorado College Studies, volume 6, 1896.

———: Observations on the Cimarron series. American Geologist, volume 19, number 5, 1897, pages 351-363.

W. F. Cummins: The Permian of Texas and its overlying beds. Texas Geological Survey, First Annual Report, 1890.

———: Report on the geology of northeastern Texas. Second Annual Report, Texas Geological Survey, 1891.

N. H. Darton: Permian salt deposits of the south-central United States. U. S. Geological Survey Bulletin, number 715, 1921, pages 205-230.

———: Geologic structure of parts of New Mexico. U. S. Geological Survey Bulletin, number 726, 1922, pages 173-275.

———: The Permian of Arizona and New Mexico. Bulletin of the American Association of Petroleum Geologists, volume 10, number 9, September, 1926, pages 819-852.

N. H. Darton and J. B. Reeside, Jr.: Guadalupe group. Bulletin of the Geological Society of America, volume 37, 1926, pages 413-428.

G. H. Girty: The Guadalupian fauna. U. S. Geological Survey, Professional Paper Number 58, 1908.

C. H. Gordon: Geology and underground waters of the Wichita Falls region, north-central Texas. U. S. Geological Survey, Water Supply Paper Number 317, 1913.

C. N. Gould: General geology of Oklahoma. Oklahoma Department of Geology and Natural History, Second Biennial Report, 1902, pages 17-74.

———: Geology and water resources of Oklahoma. U. S. Geological Survey, Water Supply Paper Number 148, 1905.

C. N. Gould: The geology and water resources of the eastern portion of the Panhandle of Texas. U. S. Geological Survey, Water Supply Paper Number 154, 1906.

——: The geology and water resources of the western portion of the Panhandle of Texas. U. S. Geological Survey, Water Supply Paper Number 191, 1907.

——: A new classification of the Permian red beds of southwestern Oklahoma. Bulletin of the American Association of Petroleum Geologists, volume 8, number 3, 1924, page 340.

——: The correlation of the Permian of Kansas, Oklahoma, and northern Texas. Bulletin of the American Association of Petroleum Geologists, volume 10, number 2, 1926, page 144.

——: Our present knowledge of the Permian of the Great Plains. Journal of Geology, volume 34, number 3, 1926, pages 415-421.

—— and F. E. Lewis: The Permian of western Oklahoma and the Panhandle of Texas. Oklahoma Geological Survey, circular 13, 1926.

—— and Roy A. Wilson: The Upper Paleozoic rocks of Oklahoma. Oklahoma Geological Survey Bulletin, number 41, 1927.

H. W. Hoots: Geology of a part of western Texas and southeastern New Mexico. U. S. Geological Survey, Bulletin Number 780-B, 1925.

P. B. King: The geologic structure of a portion of the Glass Mountains of west Texas. Bulletin of the Amercian Association of Petroleum Geologists, volume 10, number 8, September, 1926, pages 277, 944.

W. T. Lee and G. H. Girty: The Manzano group of the Rio Grande Valley, New Mexico. U. S. Geological Survey Bulletin, number 389, 1909, pages 1-141.

——: General stratigraphic break between the Pennsylvanian and Permian in western America. (Abstract.) Bulletin of the Geological Society of America, volume 28, 1917, pages 169-170.

——: Notes on the Manzano group, New Mexico. American Journal of Science, fourth series, volume 49, 1920, pages 325.

F. B. Plummer and R. C. Moore: Stratigraphy of the Pennsylvanian formations of north-central Texas. University of Texas Bulletin, number 2132, June, 1921.

C. S. Prosser: Revised classification of the Upper Paleozoic formations of Kansas. Journal of Geology, volume 10, number 7, 1920, pages 703-737.

G. B. Richardson: Reconnaissance in trans-Pecos Texas, north of the Texas and Pacific Railway. Texas Mineral Survey, 1904, pages 93-98.

——: Stratigraphy of the Upper Carboniferous in west Texas and southeast New Mexico. American Journal of Science, fourth series, volume 29, 1910, pages 325-337.

J. A. Udden: Potash in the Texas Permian. University of Texas Bulletin, number 17, March, 1914.

——: The deep boring at Spur. University of Texas Bulletin, number 363, October, 1914.

J. A. UDDEN: The age of the Castile gypsum and the Rustler formation. American Journal of Science, fourth series, volume 40, 1915, pages 151-156.

———: Notes on the geology of the Glass Mountains. University of Texas Bulletin, number 1753, September, 1917.

W. E. WRATHER: Notes on the Texas Permian. Bulletin of the southwestern Association of Petroleum Geologists, volume 1, 1917, pages 93-106.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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CLOUDBURST ON SAN GABRIEL PEAK, LOS ANGELES COUNTY, CALIFORNIA[1]

BY JOHN E. WOLFF

(*Read before the Cordilleran Section January 29, 1927*)

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INTRODUCTION

The sporadic but intense rains, known in the Southwest as cloudbursts, have in that arid and semiarid land extraordinary erosive power. Though cloudbursts occur frequently and their results are well known in a general way, accurate records of rainfall and detailed accounts of the work done by their ensuing floods are rare. Because of the present interest in floods in Los Angeles County, California, accurate records of the rainfall in a cloudburst on Rocky Gulch, in the San Gabriel Mountains, on April 4, 1926, are available and a description of the geologic results will be of interest to geologists. A number of papers on floods in the vicinity of Los Angeles and their control have already appeared.

SAN GABRIEL MOUNTAINS

The San Gabriel Mountains are a high, bold range, about 20 miles wide, that crosses Los Angeles County with a nearly east-west trend about 30 miles inland from the sea. They separate the fertile valleys of the Los Angeles area and the coastal plain from the Mojave Desert on the north.

[1] Manuscript received by the Secretary of the Society March 12, 1927.

Almost directly north of Pasadena the southern crest of the range is formed by five high peaks. San Gabriel Peak, which rises to an elevation of 6,152 feet, is the highest and Mounts Wilson, Lowe, Markham, and Disappointment are slightly lower. All are formed of massive rocks of grano-diorite type.

These high peaks are directly in the path of storms passing from west to east and receive a greater proportion of the rain precipitated from the

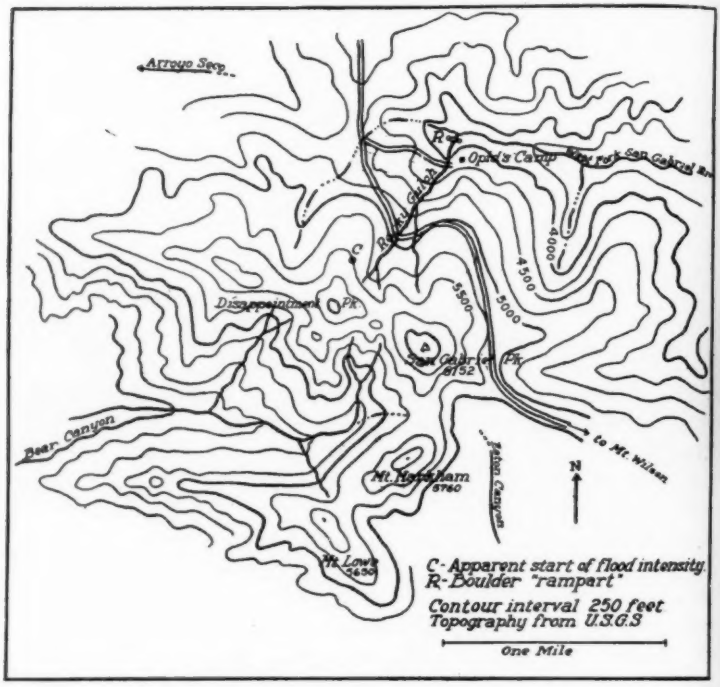

FIGURE 1.—*Map of Rocky Gulch and Vicinity*

rising air currents than the foothills on the west or the interior of the San Gabriel Mountains toward Mojave Desert. The south slopes are drained by streams which flow through deep canyons to the Los Angeles and San Gabriel rivers, but the streams of the north slopes join the interior longitudinal canyon of the West Fork of San Gabriel River, which runs eastward 17 miles to a junction with the main river, and thence southward 7 miles across the range to the plains.

Description of Rocky Gulch

San Gabriel Peak and Disappointment Peak (altitude, 6,000 feet) form the twin summits of a high ridge. In the half mile space between, there is a sag, 400 to 500 feet lower, containing a minor knob. These features are shown in the photograph, figure 2. Below this sag Rocky Gulch heads in two forks between high rocky cliffs. In a total distance of a mile the gulch descends from the hopper-like head into a more open basin with a lower grade, containing Opid's Camp, and thence drops more steeply into the West Fork of San Gabriel River.

The surface of the "basin" consists of boulders and blocks derived in part from near-by slopes, but also deposited by floods in past time. Through this cover the stream has cut a shallow and relatively broad trench. Here, in the shelter of large pine trees, is the mountain resort

FIGURE 2.—*San Gabriel Ridge and Rocky Gulch from the north*

known as Opid's Camp, consisting of numerous cabins, plainly visible in figure 2, on the banks of the stream and on the eastern side of the "basin." The proprietor, Mr. John P. Opid, is in charge of three rain-gauges, two being self-recording, located here, and has furnished part of the data on rainfall and on the local conditions not otherwise obtainable.

Rocky Gulch has a total fall from the top of the divide, at an elevation of about 5,600 feet, to its junction with West Fork, at an elevation of 3,900 feet, of about 1,600 feet in slightly less than a mile. Rocky Gulch contains a perennial stream, which is, however, of small volume in summer. It has an average grade of about 20 degrees, ranging from 32 degrees toward the head to 8 degrees in the "basin." The drainage area is 213 acres, or one-third of a square mile. In the photograph of figure 3, taken from the west side of the sag, are shown the cliffs of the extreme head of the gulch, from which great blocks loosened by weathering are supplied to the stream, which lies hidden on the left. In this

picture and that of figure 2 the contest between erosion and vegetation is evident. The trees and bushes tend to hold the debris of weathering in place, but the incipent soil and its protecting vegetation are periodically swept away, in part at least, by intense rainfalls such as the one to be described.

Cloudburst of April 4, 1926

The rainfall season, October 1, 1925, to September 30, 1926, was relatively wet, attaining a total precipitation of 50 inches, or 10 inches above the normal; but the maximum of 80 inches, recorded in 1921-1922, was not approached. A large part of the rainfall for the season 1925-1926 was concentrated in a spring storm lasting a week, during which 25 inches of rain fell. The climax of this storm occurred on April 4, when 10½ inches of rain fell in 10 hours. Following a gentle drizzle early

Figure 3.—*Head of Rocky Gulch*

in the night, at 2 a. m., April 4, rain was falling at the rate of 1.87 inches per hour, and at 3:30 the intensity reached an inch a minute, and in the second minute two-thirds of an inch.

The storm of April 4 thus had two characteristics: large quantity of water fell, 10½ inches in 10 hours, and a high intensity, since rain fell at the maximum rate of an inch a minute.

The result of this unusually intense rainfall, which would be notable in a humid region, was an immediate flood in Rocky Gulch, which lasted for an hour and a half. At Opid's Camp the water reached a depth of 25 feet and formed a channel of the same width. Large trees were swept away, several cabins were destroyed and their remains scattered for miles down the West Fork. People living at the main building, well away from and high above the stream, describe the roar of boulders roll-

ing in the waters as terrifying. This noise lasted for an hour and a half. An insignificant and ordinarily dry gulch above this building also had a flood and poured water a foot deep around the building.

Result of the Flood

The writer first visited Rocky Gulch two months after the cloudburst, and the following description is based on observations made then and on much data as to previous conditions contributed by Mr. Opid and others.

Immediately above the junction of Rocky Gulch with the West Fork the preexisting channel is filled with a great mass of large and small boulders and blocks some 60 or 70 feet wide. The lower end of this mass lies a few feet from the channel of West Fork and it extends upstream 250 feet. The grade is steep and the rise to a crest about 40 feet above the base abrupt. Beyond the crest the boulders are less numerous and the grade merges with that normal to the "basin." This pile of boulders is a veritable rampart across the path of the trickle of water that flows down the gulch in dry weather.

The photograph of figure 6 shows the crest (in the sunlight) from the upstream side, with the gorge of West Fork in the background. The photograph from which figure 7 was made was taken with an upward tilt of the camera and shows the lower part of the rampart. Some of the material at the lower right of the view antedates the flood, but as local observers state that the site was previously smooth sloping bedrock, there is no doubt that the larger part of the material is the legacy of the flood.

The shape of the blocks in the rampart is angular, but some show evidence of rounding by attrition in their journey of about a mile from the parent ledges, near the head of the gulch. The finer detritus that must have accompanied the blocks on their way downstream has been mostly carried on into the channel of West Fork.

The deposition of the rampart was due to a sudden checking of the rush of water, boulders, and sand on their entrance into the flooded channel of West Fork. Below the junction this stream had, as evidenced by stranded logs and dirt terraces, a depth of 25 feet. Above the junction it was somewhat shallower, since the area of its drainage is small and most of its tributaries come from the north, where the intensity of rainfall appears to have been small. Yet the mass of water in West Fork, the gentle gradient, and the sharp turn from Rocky Gulch into the main stream appear to have been great enough to check the current for 250 feet back from the junction.

Above the rampart in the "basin" a boulder, estimated to weigh seven tons and formed in the foundation of a cabin, was identified by Mr. Opid at a point 700 feet downstream from the cabin site. Another block of about 17 tons weight was identified by him 1,500 feet downstream from the small dam in which had been used.

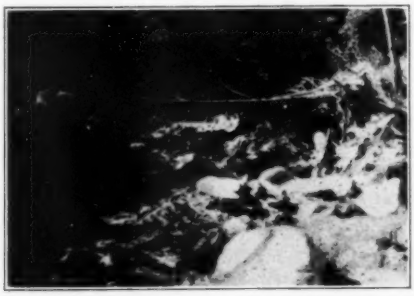

FIGURE 4.—*Stranded Log*

In the "basin" the character of the flood channel is shown in figure 4. The stranded log is two feet in diameter and rests 18 to 24 feet above the channel. It is a measure of the cross-section of the flood at this point, yet the velocity was great enough to move the boulders shown in

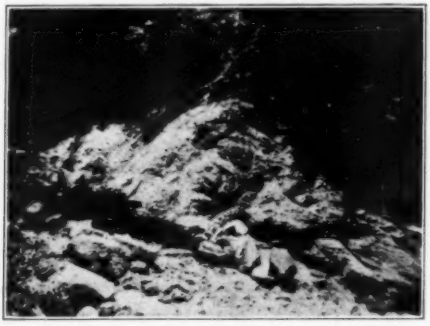

FIGURE 5.—*Scouring of Bedrock*

the view. In places, as shown in figure 5, the waters scoured to bedrock and left it bare after they receded.

At the upper end of the basin the grade of the stream steepens, and at the road crossing (altitude, 4,900 feet) the cross-section of the flood was about 12 feet square. For 200 to 300 feet below this crossing rock-

slides that obviously occurred after the flood passed have filled the channel with several feet of boulders and finer debris. This material will doubtless await another flood before it can be moved. Above, the road crossing the gulch is narrow, with steep cliffs on either side. The channel has a steep grade and a smooth rock-floor to the junction of the two

FIGURE 6.—*The Rampart from above*

upper forks at an elevation of 5,200 feet. The eastern fork has a channel covered by loose boulders, but the western fork has a rock channel that rises steeply between cliffs to the point marked "C" in figure 1, at an elevation of 5,500 feet. From this point "C," according to Mr. Opid,

FIGURE 7.—*The Rampart from below*

the water poured down over the cliffs into the gorge. It appears to have been the center of intensity of rain, although not, of course, recorded by the gauges, and the water derived from it swept clear of all loose material the western fork of Rocky Gulch. Most of the water and a

large part of the boulders, scattered as far as the rampart, appear to have been derived from this small area. The picturesque term "cloudburst" seems to apply to a storm so concentrated in its effects.

Conclusion

The geologic interest in this episode seems to lie in its catastrophic nature. Repetitions of such storms in the same place must take place at long intervals, since local people have no recollection of such an event in the recent history of Rocky Gulch. Ridges of boulders outside of and above the present channels of Rocky Gulch and of West Fork indicate that floods as great or greater have taken place. It is a happening normal to the climate and the topography, yet one that takes place only at intervals of years. The somewhat similar storm of 1915 in the mountains east of San Diego[2] produced like results and indicates that such catastrophic action plays a large part in reducing mountains under the arid but seasonal climate of south California. Bryan[3] has invoked similar action to explain the gullying of talus slopes under a climate of greater aridity in southern Arizona.

The cloudburst also illustrates the conditions of rainfall and topography competent to move in a few hours a great mass of material, containing large blocks, from the parent ledges a mile downstream. The transport will be resumed at intervals of perhaps many years by similar floods, each of which may affect only a small area in the watershed.

[2] A. J. Ellis and C. H. Lee: Geology and ground waters of the western part of San Diego Co., Calif. U. S. Geol. Survey, Water-Supply Paper 446, 1919, p. 32, pls. ix to xi.

[3] Kirk Bryan: The Papago country, Ariz., etc. U. S. Geol. Survey, Water-Supply Paper 499, 1925, p. 82-85.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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LABORATORY STUDY IN DELTA-BUILDING[1]

BY C. M. NEVIN AND D. W. TRAINER, JR.[2]

(*Read before the Society December 29, 1926*)

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INTRODUCTION

That the importance of delta deposits has long been recognized is well attested by the many descriptions of such formations, both past and present, appearing in our geological literature. Professor Barrell's[3] paper on the great Devonian delta of the Appalachian trough is an excellent illustration, while his study of the "Criteria for the determination of ancient delta deposits"[4] is one of the classics of sedimentation.[5]

Yet when one desires to really visualize the "why and wherefore" of the internal structure of a delta, and searches the literature for experiments in delta-building, a surprising meagerness is found. Some[6] have studied deltas principally from the viewpoint of the physiographer and have discussed their subaerial form. T. A. Jaggar, Jr.,[7] gave some short

[1] Manuscript received by the Secretary of the Society December 29, 1926.
[2] Introduced by Heinrich Ries.
[3] J. Barrell: The Upper Devonian delta of the Appalachian geosyncline. Amer. Jour. Sci., vol. 36, 1913, pp. 429-472, and vol. 37, 1914, pp. 87-109 and 225-253.
[4] J. Barrell: Criteria for the recognition of ancient delta deposits. Bull. Geol. Soc. Am., vol. 23, 1912, pp. 377-446.
[5] For the general literature on deltas, see Twenhofel, "Treatise on sedimentation," pp. 590-601.
[6] A. L. Smith: Delta experiments. Amer. Geog. Soc., vol. 41, no. 12, 1909, pp. 729-742.
R. S. Tarr and O. D. von Engeln: Representation of land forms in the physiography laboratory. Jour. Geog., vol. vii, no. 4, 1908, pp. 81-85.
[7] T. A. Jaggar, Jr.: Structure of esker fans experimentally studied. Abstract, Bull. Geol. Soc. Am., vol. 23, no. 4, 1912, p. 746.

conclusions in abstract, but unfortunately never published the complete report. Even the most recent literature on this subject contains little suggestion of what may be accomplished with synthetic deltas.[8]

Recognizing this lack of experimental data and appreciating the excellent results already obtained by using synthetic deltas in the laboratory, the authors feel that this subject deserves more mention than it has received in the literature. The purpose of this paper, then, is to present well established facts in a new way, a way that seems to be easily understood.

Method of building the Delta

The apparatus used in making the experimental deltas is shown in figure 1. The basin in which the deltas are formed is a tank 5 feet

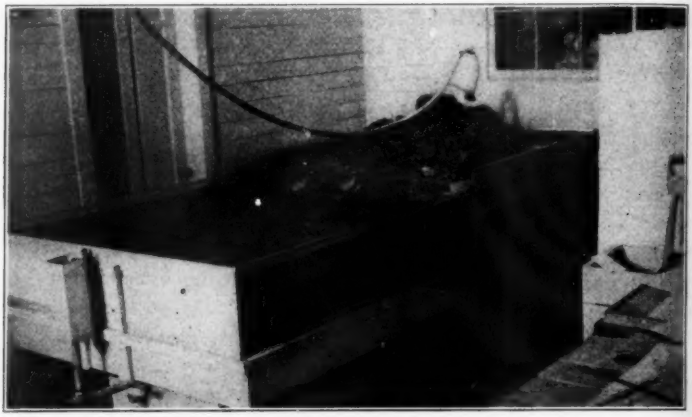

Figure 1.—*Experimental Tank for building Deltas*

square with walls a foot high, two opposite walls being of glass and the other two of metal. The whole tank is mounted on a heavy table, which raises it about 2 feet above the floor. At the center of one of the metal ends are four valves, arranged so that different water levels may be maintained in the tank. The other metal end of the tank is placed next to a platform, which is about the level of the top of the tank wall, a metal apron extending from the platform over the edge of the tank and down to the bottom. The raised platform is loaded with sediment, different types of sands and clays being kept separate, and a hose with a sprinkler

[8] H. F. Cleland: Demonstration material in geology. Bull. Geol. Soc. Am., vol. 33, 1922, pp. 65-67.

nozzle is suspended above this miniature landmass, thus providing an easily controlled water supply. Water falling on the sand or clay piles is concentrated into a single stream flowing into the tank, and the abrupt change in grade at the edge of the tank results in the water reaching the tank with a high velocity. The stream is so guided that the discharge into the tank takes place near one of the glass sides, thus making it possible to observe the structure of the delta in cross-section.

FIGURE 2.—*Variation in the Angle of the foreset Beds*

This is caused by the changing character of the sediment. Ripple-marks are preserved in the topset beds.

TRANSPORTATION OF DEBRIS BY RUNNING WATER

Even to the mature geologist, Gilbert's paper[9] on "The transportation of debris by running water" is difficult to analyze and thoroughly appreciate; yet the manner of transportation is relatively simple and is illustrated by the behavior of the stream in these delta experiments. All three modes of transportation were observed—the dune type, the smooth traction, and the interesting antidune ripple.

It was demonstrated that, with any progressive change in the conditions of the experiment which tended to increase the load, the normal phases of transportation (dune and smooth traction) disappeared and the antidune type dominated. These ripples of debris movement were caused by rhythms of the water, as stated

[9] G. K. Gilbert: The transportation of debris by running water. U. S. Geol. Sur. Prof. Paper 86, 1914.

by Gilbert, which in turn were often initiated by some small obstacle in the stream channel or by a slump of the beds at the delta front. Oftentimes these ripples are preserved and in several of the illustrations they are noticeable.

Moreover, the dependence of the grade of the stream bed itself on the velocity, amount of load, and size of debris is clearly shown. It is usually a surprise to discover how sensitively and delicately the stream bed is adjusted to the above factors.

DELTA-BUILDING

A delta has been defined as "a deposit, partly subaerial, built by a river into or against a body of permanent water."[10] Perhaps exception should be taken to the use of "permanent" in this definition, as many of our most easily observed deltas have been formed in lakes, which are commonly used as illustrations of temporary conditions. The suggestion is therefore advanced that "bodies of standing water" would be a more

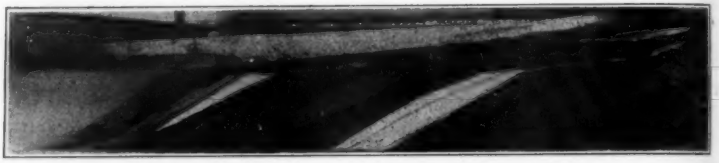

FIGURE 3.—*Delta formed under constant Conditions of Water Level*

appropriate term, especially since permanent is a word that fits in rather poorly with geological processes.

The typical fanshaped delta is not developed in this series of experiments because of the interference of the glass side, only half of the true form being obtained. However, the control of the delta shape by the continual migration and interlacing of the stream is very evident. Without guidance or direction, the initial stream soon builds natural levees, and this process continues until the stream is flowing in a channel considerably above the level of the delta plain.

In this stage the stream is not in equilibrium with its surroundings, and a slight increase in volume or an undercutting will break the levee, the stream either dividing or entirely leaving its previous channel. By continually repeating this process, the stream controls and fashions the subaerial shape of the delta.

[10] J. Barrell: Criteria for the recognition of ancient delta deposits. Bull. Geol. Soc. Am., vol. 23, 1912, p. 381.

The place of deposition for any single particle brought by a stream into a body of standing water is in general determined by the point of equilibrium between the horizontal component of the stream's velocity plus the buoying force of the water and the vertical component of the stream's velocity plus the attraction of gravity for the particle. Foreset, topset, and bottom-set beds, with their different angular relations, illustrate this fundamental principle.

FIGURE 4.—*Effect of deposition under constant Water-level Conditions*

Lower third deposited in constant water level; upper two-thirds formed in a rising water level of varying rapidity.

Usually in a body of water free from current, the angle of the delta front is determined by the subaqueous angle of repose of the sediments in the foreset beds being formed. With a stationary water level, the average angle noted for sandy material was 30 degrees, while clayey foresets averaged 20 degrees or less. This relation is illustrated in figure 2, which shows a delta made up of sediments of varying character, the difference being sharply reflected by a change in the angle of the foreset beds.

Under such conditions the clayey beds will show a thickening downward, while the sandy beds will thicken upward. Moreover, these natural angles of repose may be considerably reduced by increasing the speed of the stream, so that the horizontal component of the stream's velocity will sweep material onto the bottom-set beds beyond its ordinary position.

That additional adjustments are constantly being made at the delta front is illustrated by the many slides and slumps occurring there. These are due to an oversteepening of the subaqueous angle of repose in the foreset beds and subsequent loading.

Figure 3 is another view of the same delta and gives an idea of the type of

cross-section one would expect to find in a delta formed under stationary conditions of water level. The large development of foreset beds, due to the delta's growth outward, is well illustrated.

Contrast this with figure 4, where the beds were deposited in a rising water level. Theoretically, if deposition exceeded this rise in water level, for every topset bed there should be formed an equivalent foreset. If, on the other hand, the water level rose more rapidly and gained on the volume of deposits, few, if any, foreset beds would be in evidence. These varying conditions illustrate the usual type of delta deposited on a sinking bottom with the characteristic formation of many topset beds.

As a final illustration, the water level is allowed to fall gradually and uniformly. Erosion of the topset beds will begin immediately, the material being carried out to form foreset and bottom-set beds. Usually the velocity of the stream is quickened and much of the sediment is carried

FIGURE 5.—*Tearing down and extending of a Delta in a falling Sea*

a considerable distance beyond the delta front, which results in the foreset beds being formed at an unnaturally low angle. Figure 5 shows this condition.

LENSES

The illustrations already shown have demonstrated that it is possible to produce lenticular effects in the foreset beds by varying the sedimentary materials and their angles of repose. In addition, the topset beds frequently show lenses because of changes in the velocity, in the amount, or in the character of the load of the stream. The scouring and filling produced by these variations results in local lensing. This tends to break up the continuity of the topset beds, so that very seldom is one able to trace a topset bed throughout its entire length and into the corresponding foreset bed. The usual text-book illustration of a delta showing a complete topset bed for each foreset bed would not apply to these conditions of delta-building.

Summary

It is appreciated that the torrential deltas here described have been formed under conditions rather different from those usually found in the discharge areas of our large rivers. Natural torrential environments, comparable to those of the laboratory experiments, are, however, common in glacial lakes, and today many deltas with characteristic steep fronts and largely developed foreset beds are being formed by glacial streams.

An almost perfect duplication of figure 6 is found in the many fossil deltas of the former glacial lakes of central New York, which were

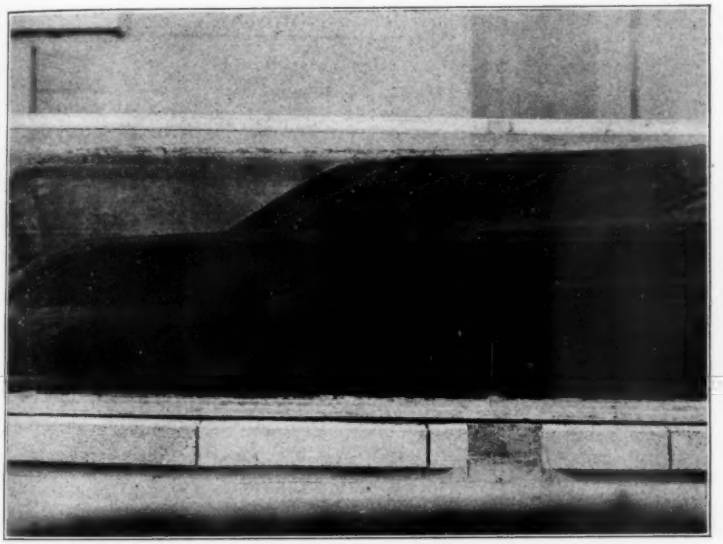

FIGURE 6.—*Delta formed by abrupt Rises in the Water Level*

deposited under torrential conditions in lakes whose levels changed abruptly. The resulting flat-topped, cross-bedded deltas form a series of giant steps that accurately mark the former falling lake levels. Exactly the same result may be produced in the laboratory by filling the tank to successively higher levels during the delta-building.

Perhaps the most interesting delta, from the viewpoint of one studying sedimentation, is that which has been built on a slowly subsiding bottom. Such a delta environment has contributed enormous deposits in the past, and the great delta areas of today are usually of this type. The

Devonian deposits of the Appalachian trough, composed almost entirely of topset beds, are an example from the past, while the Mississippi Delta area is a present illustration. Parallel results are obtained in the laboratory by gradually raising the water level during delta-building, thus controlling the relative development of topset beds.

Finally, this method of demonstrating the transportation and deposition of debris illustrates one of our most important geological processes and has met with gratifying success in teaching sedimentation.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 38, PP. 459-468 SEPTEMBER 30, 1927

NEW FACTS CONCERNING THE SAINT PETER SANDSTONE OF ILLINOIS[1]

BY J. E. LAMAR[2]

(Presented before the Society December 29, 1926)

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INTRODUCTION

The Saint Peter sandstone of Illinois is so well known, as to its general characteristics, that it needs no introduction. The purpose of this paper, therefore, is to call attention to a number of unusual phenomena observed during a State-wide study of the sandstone for the Illinois Geological Survey. Some of the phenomena described have been noted by earlier writers, but their records have been too meager and too generalized to be entirely satisfactory.

Although the Saint Peter underlies almost all of Illinois, it outcrops in a very limited area (figure 1). The principal exposure occurs in the Ottawa-Utica area, in the north-central part of the State. Others in order of importance are in the Oregon-Dixon area, about 40 miles northwest of the Ottawa-Utica district; in the Brookville-Harper area, about 60 miles northwest; and near Shirland, close to the center of the north

[1] Manuscript received by the Secretary of the Society January 4, 1927.
[2] Introduced by M. M. Leighton.

FIGURE 1.—*Map of Illinois showing Location of Outcrops of Saint Peter Sandstone*

boundary of the State. In Calhoun County, in west-central Illinois, the Cap aux Gres fault and erosion have exposed the sandstone.

For many years the sand forming the Saint Peter was thought to have accumulated as a great inland desert deposit. Dake's recent work[3] on the sandstone, however, has been influential in crystallizing geologic opinion in favor of marine accumulation as the chief mode of origin. The study of the sandstone in Illinois further confirms the marine origin in general, with the exception of certain horizons in certain places.

Sedimentary Structures

General statement

It seems probable that if the Saint Peter were less pure, of more uneven texture, and had greater localization of the clay content, such phenomena as cross-bedding, ripple-marks, and the like might be found more frequently, whether the sand was deposited by wind or water. Discounting, however, the possible lack of favorable conditions for the formation of such structures during the accumulation, the fact remains that they are extremely rare in the outcrops and artificial exposures of the sandstone in Illinois. Cross-bedding and ripple-marks, although very uncommon, may occur at any horizon, but worm-borings and sun-cracks are found only in those beds of fine texture and high clay content in the middle of the formation.

Ripple-marks

The most numerous ripple-marks were found near the middle of the lower portion of the formation exposed north of Dogtown Landing, in the southwest corner of section 29, township 12 south, range 2 west, in Calhoun County, western Illinois. They have been subject to erosion by the Mississippi River, and as a consequence, though entirely recognizable, are somewhat indistinct as to structural details. They are probably of the oscillation type and vary from 1 to 1½ inches in wave-length and average about one-fourth inch in amplitude. In the Oregon-Dixon area, in northern Illinois, the basal portion of the sandstone is locally ripple-marked. The best exposures occur in the north valley wall of Franklin Creek, in the northeast corner of section 3, township 21 north, range 10 east, and in the northeast quarter of the northwest quarter, northeast quarter, section 33, township 22 north, range 10 east. They are of the oscillation type. In some exposures they parallel each other

[3] C. L. Dake: The problem of the Saint Peter sandstone. School of Mines and Metallurgy, University of Missouri, 1921.

FIGURE 2.—*Ripple-marks in the Saint Peter Sandstone*
This occurrence is in section 3, township 21 north, range 10 east.

and have a wave-length of about one inch and an amplitude of one-fourth to one-half inch (figure 2); at other places they anastomose and have a wave-length of 1½ to 3½ inches and an average amplitude of about one-half inch. The trend of the troughs is roughly north 30 degrees west. Ripple-marks are also common in the upper Saint Peter strata, exposed northwest of Shirland, in northern Illinois, near the center of section 32, township 29 north, range 11 east, in the south bank of Sugar River. None of eolian type, such as are noted by Worthen,[4] were observed. The ripple-marks of the Illinois Saint Peter suggest local shallow-water conditions.

FIGURE 3.—*Cross-bedding in the Saint Peter Sandstone*

This is best shown in the lower right-hand corner. The thin-bedded stratum just above the middle of the picture is 14 inches thick. It contains worm-borings.

CROSS-BEDDING

Cross-bedding, though rare, as previously stated, was noted most commonly in the middle Saint Peter of the Ottawa-Utica district, particularly in the quarries of the United States and Wedron Silica Companies, located respectively in the southwest quarter of section 16, township 33 north, range 3 east, and in the southwest quarter of section 9, township 34 north, range 4 east (figures 3 and 4). The thickness of the cross-bedded sandstone varies from about 1 to 8 feet, and its texture is not strikingly different from that of the formation generally. In the quarry

[4] A. H. Worthen: Geology of Illinois, vol. III, 1882, p. 18.

of the former company (figure 3) two types of this phenomenon are exposed: The first consists of a single cross-bedded stratum about three feet thick and probably of marine origin, lying between horizontal beds of much greater thickness; the second, of false bedding inclined in a number of directions, with the different sets of beds truncating, or truncated by, others and conceivably of either eolian or water origin. In the sandstone generally the cross-bedding is more characteristic of water than of wind deposits and points to shallow water and possibly local terrestrial conditions in the Ottawa-Utica district of Illinois.

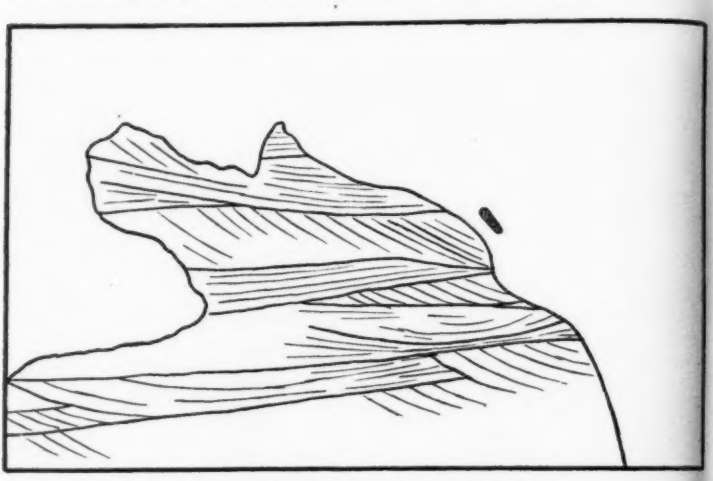

FIGURE 4.—*Cross-bedding in the Saint Peter Sandstone*

The shield was made from a photograph made in the quarry of the Wedron Silica Company. The knife indicates the relative size of the beds.

WORM-BORINGS

In the vicinity of Ottawa some of the fine-grained beds of the middle Saint Peter sandstone contain numerous worm-borings (figure 5). Similar features were also noted by Freeman,[5] but in the basal portion of the sandstone. The borings vary from one-eighth to one-fourth inch in diameter and are filled with sand which is noticeably coarser than the matrix in which they occur. The best exposures were found in the quarry of the United States Silica Company (figure 3), in the 14-inch thin-bedded stratum, and in a similar bed in the quarry of the Commonwealth Silica Company at the center of the south line of the northeast

[5] S. H. Freeman: Geology of Illinois, La Salle County, vol. II, 1882, p. 228.

quarter of section 18, township 33 north, range 2 east. The worm-borings give evidence of shallow-water conditions in the Ottawa-Utica area.

SUN-CRACKS

In the northeast corner of the glass-sand quarry of the Higby-Reynolds Silica Company, located in the southwest corner of the northwest quarter of the southeast quarter of section 9, township 33 north, range 2 east,

FIGURE 5.—*Worm-borings in the Saint Peter Sandstone*
Specimens taken from the quarry of the United States Silica Company.

near Utica, a fine-grained stratum high in clay contains somewhat indistinct yet recognizable markings, thought to be sun-cracks. They are of fairly large size, the individual rays of the cracks averaging 6 or 8 inches in length. The presence of sun-cracks in the middle Saint Peter sediments of the Ottawa-Utica area suggests conditions of deposition varying between shallow water and terrestrial. The stratum containing these markings is of middle Saint Peter age and is conformable with the beds above and below it.

Limestone in the Saint Peter

Although limestone is commonly reported in the upper Saint Peter in the logs of wells penetrating the formation in northeastern Illinois, and also, but more rarely, in western Illinois, no limestone or other calcareous beds were observed in any outcrops of the sandstone proper except the calcareous zones in the upper portion of the formation in Calhoun County. This distribution of the calcareous beds and the presence of sun-cracks and worm-borings in the Ottawa-Utica area is thought to indicate that the deeper portion of the Saint Peter sea lay east and also probably west of the Ottawa-Utica and Oregon-Dixon areas.

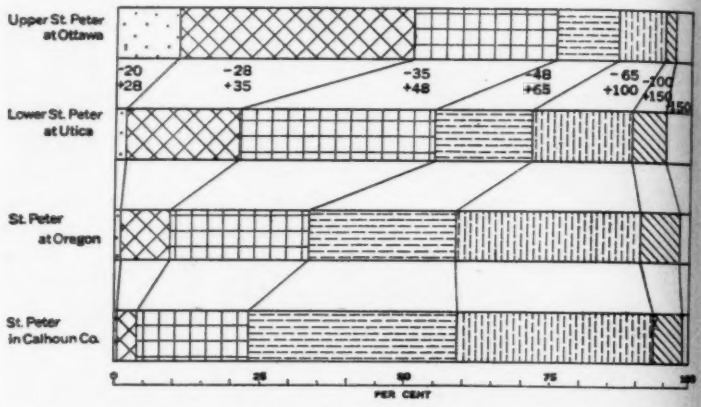

FIGURE 6.—*Average sieve analyses of Saint Peter Sandstone in four Areas of Outcrop*

Variation of Regional Texture

Figure 6 shows graphically average sieve analyses of the Saint Peter sandstone in the Ottawa-Utica, Oregon-Dixon, and Calhoun County districts. The outstanding feature of these graphs is the greater coarseness of the sandstone in the Ottawa-Utica district, despite the fact that this area is farther from the probable source of the sand than either of the other two areas mentioned. These data, though not necessarily proof of more generally shallow-water conditions in the Ottawa-Utica district than in the other areas mentioned, are distinctly in accord with that hypothesis.

Pitting of the Sand Grains

The minute pits associated with the frosted surfaces of the Saint Peter sand grains and generally assigned to abrasion are well known. Two other types of pits present (figure 7) are worthy of mention: First, those formed by the deposition of secondary silica about grains of sand in contact, but not at the points of contact, thus producing pits in more or less euhedral grains with the frosted surface of the original grain in

FIGURE 7.—*Interlocking Grains and Pits and Scars developed by Solution*
The interlocking grains are shown at the upper right, and the pits and scars at lower right and left.

many cases visible in the bases of the pits. The second type of pit is due to solution of silica from grains at the points of contact with other grains, so that either both grains are truncated alike by the solution, or more of one grain is dissolved than of the other, and the latter protrudes into the solution depression in the former. In case of approximately equal solution from both grains, scars are formed; in the case of unequal solution, shallow pits resembling lunar craters. The largest pit noted was 0.4

millimeter in width and 0.1 millimeter in depth, but commonly they are from 0.1 to 0.3 millimeter in width. Some of the solution pits are much eroded and rounded and apparently were formed while the grains which contain them were a part of some earlier sandstone.

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AGE OF THE RED CLASTIC SERIES OF MINNESOTA[1]

BY CLINTON R. STAUFFER

(*Presented in abstract before the Society December 27, 1926*)

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INTRODUCTION

Barren sediments are often as difficult to classify, in respect to their age, as certain igneous and metamorphic rocks. This lack of age determination has long been the status of some of the old sandstones and shales of eastern Minnesota. In the region to the southward, from the Lake Superior district to the Iowa State line, about twenty-five wells, some of recent date, have penetrated or passed through these deposits and have thus continually called for a more definite correlation of the sands and shales in the deeper part of these logs. In order to arrive at more satisfactory conclusions in regard to their age, some time has been devoted to them, during the last two years, with the results as given herewith.

THE RED CLASTIC SERIES

In eastern and southeastern Minnesota there is a great thickness of red sediments lying below the Saint Croix Series and above the usual rocks of the pre-Cambrian. The lower part of this deposit consists of alternating shales and sandstones in which the prevailing color is red, although grays and greens are not wanting. Conglomerates also appear, and in

[1] Manuscript received by the Secretary of the Society December 20, 1926.
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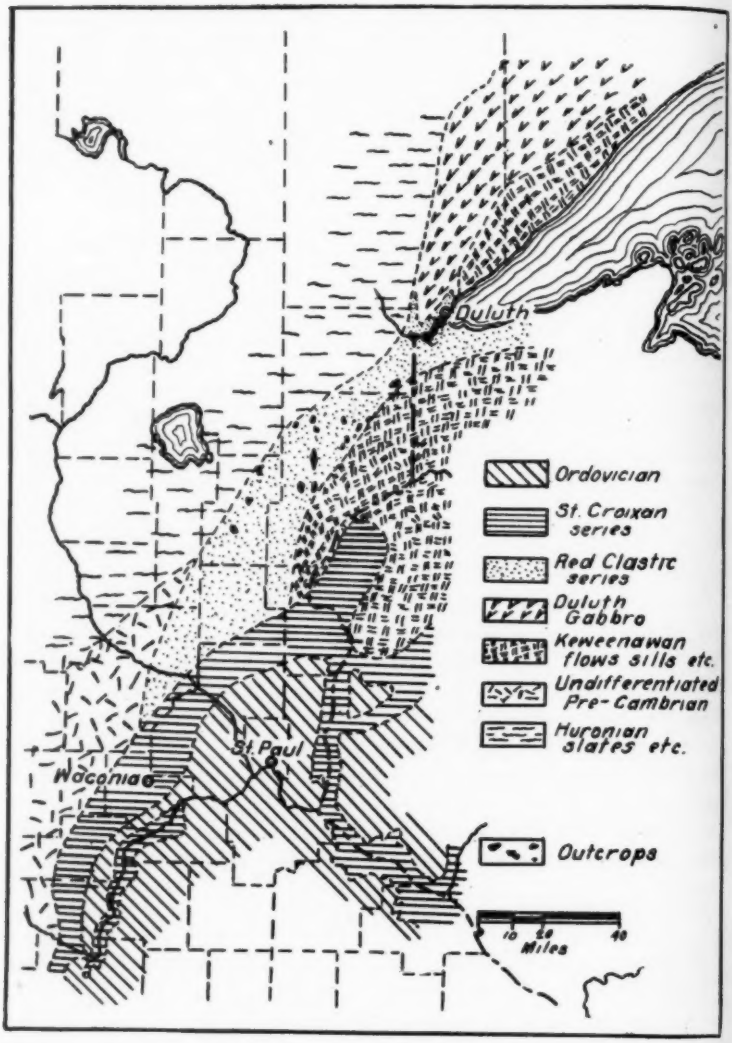

FIGURE 1.—*Map showing Location of Waconia and the Distribution of Outcrops of the Red Clastic Series in Minnesota*

Mainly after Dr. F. F. Grout, Journal of Geology, volume XVIII, page 635; volume XXXVI, page 446.

some cases these may be quite thick. At the top occurs a thick, coarse, red to brown sandstone which often contains much partly weathered feldspar, together with mica, magnetite, and traces of other minerals. It may be either massive or shaly and sometimes shows the marks of shallow-water deposition. This is the Hinkley sandstone, which lies immediately below the Saint Croix Series and may be recognized over wide areas, even in the records of the deep wells of southern Minnesota.

Previous Correlations

These red shales, including the Hinkley sandstone, have been correlated with similar deposits in Wisconsin and Michigan, and the whole has lately been referred to the Keweenawan.[2] N. H. Winchell regarded them as a part of the Upper Cambrian and used the name "Potsdam"[3] for the whole series. In this he was followed by C. W. Hall[4] and Warren Upham, but later Hall, Meinzer, and others called this deposit the Red Clastic[5] Series and rather doubtfully referred it to the Keweenawan Series, probably because of its relationship to the lava flows of the Lake Superior region and which latter have generally been regarded as Algonkian. Certain it is that these beds are difficult to relate to anything definite in the stratigraphic column. They are usually covered by the well recognized Cambrian, and where this is not the case the outcrop is seldom free from the heavy mantle of drift that obliterates so much of our geology.

Outcrops

The best Minnesota outcrop of the Red Clastic Series, free from glacial debris, is that along the Saint Louis River at Fondulac, where the measured thickness lies somewhere between 412 feet, as given by Winchell,[6] and 730 feet, as given by Thwaites.[7] Other outcrops occur along the Kettle River in Carleton and Pine counties and along the Snake River north of Mora, in Kanabec County.

Well Logs

Southward from the outcrops the series is known only from well records, of which there is a goodly number, sufficiently spaced[8] to insure

[2] F. T. Thwaites: Wisconsin Geological and Natural History Survey, Bull. 25, 1912, pp. 102-109.
[3] Geological and Natural History Survey of Minnesota, Tenth Ann. Rept., 1881, p. 34.
[4] Minnesota Academy of Science, vol. 3 (1886), 1891, p. 135.
[5] United States Geological Survey, Water Supply Paper No. 256, 1911, p. 48 and pl. vi.
[6] Op. cit., pp. 30-34.
[7] Op. cit., pp. 70-73.
[8] Bulletin of the Geological Society of America, vol. 12, 1901, pp. 320-321.

continuity of deposition, to the Twin Cities and southern Minnesota, where the series is very thick.[9] A recent well, showing a fine section, was drilled at Rochester during 1923-1924. Of this the following is a record:

Log of the deep Well drilled two Miles East of Rochester, Minnesota

Formation	Thickness, feet	Total depth, feet
Drift:		
Yellow clay	9	9
Platteville limestone:		
Limestone, dolomitic, gray to bluish	21	30
Saint Peter sandstone:		
Sandstone, soft white	92	122
Shakopee and Oneota dolomites:		
Dolomite, buff to brown	304	426
Jordan sandstone:		
Sandstone, gray to white	79	505
Saint Lawrence formation:		
Dolomite	127	632
Franconia formation:		
Shale, sandy green	142	774
Dresbach formation:		
Shale and sandstone	76	850
Eau Claire (?) formation:		
Shale, gray	118	968
Sandstone and shale	18	986
Hinkley sandstone:		
Sandstone, very hard	206	1,192
Red Clastic Series:		
Shale, red, and sandstone	96	1,288
Shale, red, hard and heavy with iron; some quartz sand	33	1,321
Sandstone, coarse, clear	23	1,344
Shale, red, alternating with sandstone; mostly shale with very hard streaks of pink and red shale	110	1,454
Sandstone, nearly clear	3	1,457
Shale, red, alternating with sandstone	91	1,548
Sandstone, with streaks of conglomerates as coarse as wheat	4	1,552
Shale, red, alternating with sandstone	184	1,736
Shale, red, mixed with coarse sand	6	1,742
Shale, hard red, with some sand (said to have had a showing of oil between 1,915 feet and 2,100 feet)	389	2,131
Sandstone, clear streak	3	2,134

[9] A. D. Meeks: Minnesota Academy of Science, vol. 3, (1887-89), 1891, pp. 274-277.

Formation	Thickness, feet	Total depth, feet
Shale, red, alternating with sandstone	167	2,301
Sandstone, bearing salt water	23	2,324
Shale, red, alternating with sandstone	598	2,922
Shale, red, with streaks of limestone	6	2,928
Shale, red, alternating with sandstone	9	2,937
Shale, hard, red	152	3,089
Shale, light red	12	3,101
Shale, hard, red	35	3,136
Shale, red	9	3,145
Shale, red, alternating with sharp-grained sandstone	21	3,166
Shale, red, very tough	24	3,190
Shale, light green	35	3,225
Pre-Cambrian:		
Red granite	4	3,229
Biotite schist	36	3,265

This section, which shows a thickness of 2,033 feet for the Red Clastics and 206 feet for the Hinkley sandstone, may be considered as typical of the series as it occurs in the deep wells of Minnesota. It resembles very closely the outcrop along Saint Louis River, in that the red shales alternate with layers of sandstone not all of which are red. The interpretation here given is based on the driller's record. Considerable secrecy was maintained during the drilling of this well and only a small portion of the cuttings was made available for study. These showed no evidence of fossils.

Another well, at Waconia, completed in October, 1924, was drilled for a city water supply. Fortunately the record and accompanying cuttings were available for examination, and thus the various types of rock penetrated are known with a greater degree of certainty.

Log of the City Well drilled at Waconia, Minnesota

Formation	Thickness, feet	Total depth, feet
Drift:		
Clay	55	55
Sandy clay	10	65
Clay	149	214
Sand	90	304
Gravel	161	465
Saint Lawrence formation:		
Shale, dolomitic, red	25	490
Shale, green, with layers of dolomitic sandstone, and some greensand partings; *Dicellomus politus* abundant	11	501

Formation	Thickness, feet	Total depth, feet
Shale, light green, with numerous specimens of *Acrotreta ophirensis* and an occasional *Ptychoparia* sp.	26	527
Franconia sandstone:		
Sandstone, fine grained, with greensand partings; *Dicellomus politus* abundant	70	597
Dresbach formation:		
Sandstone, gray, with fragments of *Dicellomus politus*	71	668
Shale, argillaceous, gray, with *Dicellomus politus*	2	670
Hinkley sandstone:		
Sandstone, coarse, pink to gray, well rounded quartz grains	20	690
Red Clastic Series:		
Shale, argillaceous, red, near the bottom containing the following fauna: *Acrothyris proavia ?* (Matthews), *Acrotreta attenuata* Meek, *Acrotreta ophirensis* Walcott, *Acrotreta pyridicula* Walcott, *Acrotreta*, sp., *Lingulella nanno ?* Walcott, *Obolus* sp., *Asaphiscus* sp., *Bathyuriscus* sp., *Ptychoparia cadance* Walcott	45	735
Shale, red, with grains of quartz	101	836
Shale, red, with a few rounded grains of quartz	4	840

Although a comparatively shallow well, this is the most interesting, from the geological standpoint, of any thus far drilled in the State. The Hinkley sandstone is unusually thin, but typical of the formation wherever known. The importance of the record, however, lies in the fauna found in the drill cuttings.

Fauna and Age

Owing to the unsatisfactory outcrops of the Red Clastic Series in Minnesota, it has been impossible to search these deposits with sufficient thoroughness to determine the existence of fossils. Anyone who has seen these fine red shales, still but slightly consolidated and only tilted from their original position by a small angle, must wonder that remnants of the life of the time are so rare or wanting, but careful examination of the outcrops has not rewarded the geologist with definite fossil, although there is still hope that they may be found.

The fauna of the Red Clastic Series found in the cuttings from the Waconia well occurs about 40 feet below the base of the Hinkley sandstone. As far as known, it consists of seven brachiopods and three trilobites. The brachiopods are fairly abundant but exceedingly small.

The trilobites are not abundant and one at least is small. In fact, the whole fauna is such that it might easily be overlooked, even in a careful search, and especially since it probably occurs in a very thin stratum in the midst of barren shales of like consistency throughout.

This fauna resembles that found in the Middle Cambrian of Montana, Wyoming, Utah, and Idaho. Indeed, part of the forms from the Red Clastic Series have been identified with the species that Walcott[10] described from that western region, and those remaining resemble still others of the same fauna. In other words, the shales in which this fauna occurs are Middle Cambrian. Possibly the whole of this great Red Bed deposit should be referred to the Cambrian, but this affects likewise the lava flows of the Keweenawan, part of which, at least in the Duluth region, is suspected of being interbedded[11] with the Cambrian Red Beds. There is probably no valid reason why even the lavas may not be of Cambrian age.

Discussion by Alfred C. Lane

The Red Clastic Series may well be both Middle Cambrian and Keweenawan; for, in the belief which I have long held, the Keweenawan conformably underlies the Lake Superior sandstone of the Upper Cambrian which appears in the Apostles Islands. This was for a long time believed to be of the same age as the sandstone around Limestone Mountain and Baraga, on the other side of Keweenaw Point, which is beyond doubt Upper Cambrian.

I well remember going over the section with Leith around the Oronto River and his recognition of the probabilities and sending in Thwaites, who made careful studies which confirmed my conclusions. But the result was to remove the Apostles Islands from the Cambrian in the maps prepared later than Monograph 52 (see page 616), and to place the dividing line between the sandstones and the Cambrian sandstones of the Mississippi Valley in a heavily drift-covered area.

If any one will read the argument for the pre-Cambrian age of the Keweenawan (page 416), he will see that room is left for the continuation of the Keweenawan upward without break into the Upper Cambrian, and that the arguments for the pre-Cambrian age, however weighty, are by no means conclusive. Moreover, some of the arguments have been decidely weakened by the discoveries since the publication of Monograph 52.

[10] Smithsonian Misc. Coll., vol. 67, 1917, pp. 9-59.

[11] N. H. Winchell: Geological and Natural History Survey of Minnesota, Bull. 5, 18—, pp. —. Also, Geology of Minnesota, vol. 4, 1899, pp. 567-571.

Let us take them in order as given there:

1. "The Cambrian is fossiliferous and the Keweenawan is not." We have now reported fossils in strata which have hitherto been called Keweenawan. Moreover, the Keweenawan, as we all agree, is very largely a volcanic and land formation. How frequently are fossils found in such a formation in the "Red Beds"? On the occasion referred to I remember saying to Leith, "What kind of land fossils would you expect to find in the Cambrian?"

2. "The Cambrian is largely a subaqueous deposit, the Keweenawan is largely subaerial." Granted! It applies also to the Alpine and German Trias, the Scotch Old Red Sandstone, and the Devonshire Devonian. There is much more difference in facies in coeval formations in those periods than in the Apostle Islands and Freda sandstone or Western sandstone and the Eastern sandstone, which were considered identical for a century.

3. "The Cambrian contrasts with the Keweenawan in lacking volcanics." This we know now is not strictly true. Contemporary volcanics have been recognized in the Appalachians by Watson and Cline, and in fact we know now from the paper by Stose at this meeting and the work of Nelson, Sardeson, and others on Bentonite that a little vulcanism lasted into the Ordovician. On the other hand, the upper Keweenawan shows a marked and steady waning of volcanic activity.

4. "The known Upper Cambrian is almost flat lying." True except at Limestone Mountain; but, as I showed in my paper on the Keweenaw fault, which Leith was kind enough to commend, there are signs of late Paleozoic disturbances affecting both.

5. "The Keweenawan as a whole is tilted." True, but much less so at the top, and it does not partake of the large system of mountain flexures running east and west, and associated with the Killarney granite, which Cooke, Quirke, and especially Collins, have been emphasizing of late years. Moreover, as the Wisconsin work has lately shown, there is marked discordance between the Keweenawan, especially the upper Keweenawan, and the previous beds.

Also, the arguments from pleneplains have been modified by recent Canadian work, showing various paleoplains and one over outliers of Paleozoic like Laurentian Mountain!

Time and papers like this and that of Stose and Jonas have only strengthened in my mind the arguments which I presented in my report on the Keweenaw Series (page 940) for the Cambrian age of the Keweenawan.

On the whole, the Keweenawan of Keweenawan Point is a series of coarse and largely volcanic beds formed after a period of extensive uplifts and during its gradual dying out (see E. S. Moore's paper presented to the Geological Society of America last year). On the principle of Schuchert, this would mean that it belongs with the beds above, but of course, in default of fossils of the Lower Cambrian, it can only be proved indirectly that some part of it does not belong rather below the Cambrian defined as confined to the Olenellus zone; that, in other words, there may not be beds analogous to the Permian as well as analogous to the Triassic which it so much resembles. On the other hand, there is no proof that any of the Keweenawan of Keweenaw Point is pre-Cambrian.

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PONGO DE MANSERICHE[1]

BY JOSEPH T. SINGEWALD, JR.

(Presented in abstract before the Society December 28, 1926)

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INTRODUCTION

The canyons of the Amazon River system in the eastern ranges of the Andes of Peru are there known by the Indian name of *pongo*. The most famous of these is the Pongo de Manseriche, cut by the Marañon River through the eastern range of the Andes, where it emerges from the cordillera into the flat terrane of the Amazon Basin.

The Pongo de Manseriche lies nearly 500 miles upstream from Iquitos, and consequently nearly 3,000 miles above the mouth of the Amazon River. It is situated in the heart of the *montaña*, in a vast region the ownership of which has long been in dispute between Peru and Ecuador, but over which neither country exercises any police or other governmental control. The region is uninhabited except for small bands of

[1] Manuscript received by the Secretary of the Society November 26, 1926.

seminomadic Aguaruna Indians. They are a branch of the savage Jivaro Indians, known principally through their gruesome custom of shrinking the heads of their victims, specimens of which have found their way into most museums.

FIGURE 1.—*Map of upper Amazon Region showing Location of Pongo de Manseriche*

Few other than venturesome explorers and intrepid rubber men have traversed the canyon. The records of the former are written as tales of travel and adventure, are chiefly narrative, and generally abound in exaggeration of the perils of the region and the dangers of the canyon. The rubber men risk great dangers and perform wonderful feats of ex-

ploration, but are neither interested in nor capable of leaving a written account of the territory they traverse. Consequently, geographic literature contains no reliable description of the canyon, and it has never been described geologically. In the course of geologic explorations in eastern Peru in 1925, Mr. Ernest C. Roschen and I traversed the canyon in two canoes, making a plane-table survey of it. A general account of the results of that survey are presented.

Geography and Physiography

Approaches to the Pongo

The terrane of low relief so characteristic of the Amazon Basin continues along the course of the Marañon River until the very base of the

Figure 2.—*Approach to the eastern Range of the Andes from the Amazon Basin*

Cordillera Oriental is reached. As the range suddenly looms into sight on one of the reaches of the river, it looks like a well-defined, simple ridge of rather uniform elevation, except for the gap marking the position of the Pongo de Manseriche. The Marañon River has poured out into the plain for some distance below the *pongo* great masses of debris. When the river is in flood this is covered by the waters, and the river is a broad sheet of swiftly flowing water bounded on each bank by the vegetation of the tropical jungle and dotted with innumerable vegetation-covered islands; but at times of low water it threads its way swiftly through several channels between playas and islands of debris that in-

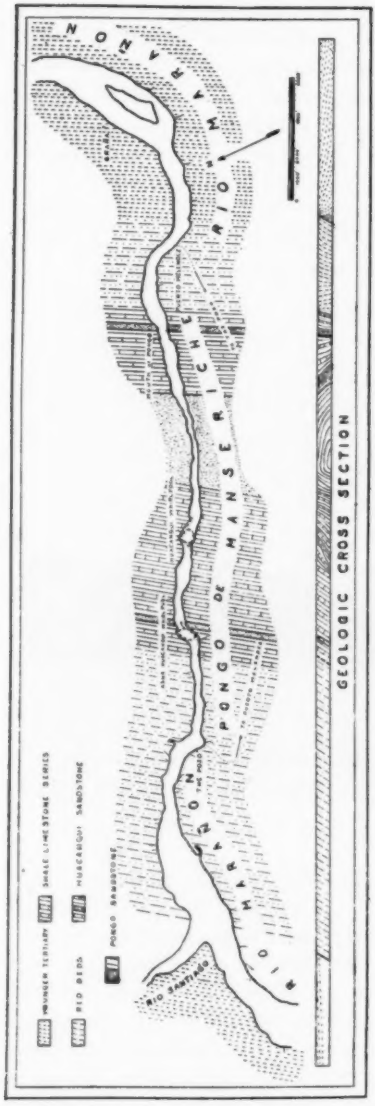

FIGURE 3.—*Map of Pongo de Manseriche and geologic Cross-section through the Pongo*

creases in coarseness from
and gravel to large boulde
the *pongo* is approached.
by means of an excee
winding and anastor
course has the river beer
to make its way acro
mantle of debris that ha
spread out in front
pongo. Hence, even
the Cordillera Oriental
into view, the approach
mouth of the canyon is sl

The beginning of the
ground is near a landing
as Puerto Melendez, on the
right bank of the river. Here
the river is not quite 600 feet
wide, whereas one mile down-
stream it has a width of 2,000
feet. Less than a mile above
Puerto Melendez a heavy ledge
of quartzitic sandstone projects
into the river on each bank,
constricting the river to a
width of less than 400 feet. It
may be properly regarded as
marking the mouth of the
pongo.

Above the Pongo de Man-
seriche the Marañon River
flows through a wide intermon-
tane valley with as little relief
as the Amazon Plain. The
ridge of the Cordillera Oriental
looms up on the eastern bound-
ary of this valley almost as
abruptly as it does on the op-
posite Amazon Plain side. In other directions no mountains or hills
are visible from the river. Nearly 2 miles above the entrance to the

on an important tributary, the Santiago River, debouches into the ion. Here it has a width of 2,000 feet, but within a mile down- it decreases to 600 feet, only to widen again to 800 feet at the

Pozo is a small embayment on the right bank of the river, due to osion of softer shale that lies upstream from harder, massive red one. The entrance of the river on this sandstone marks the en- to the *pongo*. The width of the river decreases to less than 500 d hills border both banks. The slack water at the Pozo affords a nding place, and at low water a large, though somewhat steep, exposed.

THE CORDILLERA ORIENTAL

to Melendez and the Pozo are connected by a dim trail that cross the range well back from the river, so that it affords no view of the canyon. It is an old trail used by the Indians and by rubber men, traces of whose work are still encountered along it. In a straight line, the distance between Puerto Melendez and the Pozo is less than 5 miles, but the route of the trail is so circuitous and the topography so accidented that it takes a loaded peon an entire day to make the trip. The top of the ridge is nearly 3,000 feet above the river.

Topographically, the Cordillera Oriental consists of a main ridge flanked on each side by lower foothills which have escarpment slopes toward the range and more moderate dip slopes away from the range. This topographic relationship of the foothills, together with the thick covering of tropical forest, explains the blending of the whole range into the appearance of a simple ridge when seen from a distance.

THE PONGO

The length of the canyon along the course of the river is 4 miles. The maximum width of the river is about 700 feet and the narrowest place is just under 300 feet. The course of the river is a succession of rapids and whirlpools. The most dangerous of the latter are Huacanqui and Asna Huacanqui. Where the course of the river is relatively straight and free from projecting ledges of rock, the current is swift, but free from marked vertical motion. Where a bend in the river or the entrance of a tributary ravine has caused the accumulation of massive debris, turbulent rapids and standing waves are encountered. Where massive ledges of hard rock project into the river, so as to constrict its cross-section and deflect sharply the current against the opposite bank, whirlpools develop, in which the vertical motion becomes so rapid that large funnel-like holes

are formed, into which the whirling water pours in immense volume with a great rush and roar.

It is difficult to give a satisfactory description of the waters of the Pongo, as their mood changes with every change in the stage of the river. Even at the same level, there is a tremendous difference at the difficult and dangerous points, not only according as the river is rising or falling, but also according to the rate of the rise or fall. When the water is rising, it accumulates back of the narrow points faster than it can be discharged, and pours through those places with a rush as over a cascade. When the water is falling, the pressure back of the narrow points is greatly lessened, and the wildest and most dangerous places in the canyon become relatively calm. Thus we had to wait ten days after

FIGURE 4.—*Entrance to the Pongo de Manseriche, looking Upstream*

our arrival at Puerto Melendez before the river was low enough to make it possible to begin our survey through the canyon. While we were surveying the canyon the river fell still more, and Colonel Morrell, a member of our expedition, made the trip from Puerto Melendez to above the Pozo and back in half a day without any difficulty whatever. Indeed, as his canoe passed us on its way downstream we experienced a feeling of disappointment to see how uneventful the descent of this famous canyon was. Several days later we descended the river when it had risen 15 feet, and our passage was quite different. Although we lashed *topa* logs to the sides of the canoes to steady them and give them greater buoyancy, one canoe narrowly escaped being drawn into the vortex of the

Asna Huacanqui Whirlpool and the other was overturned in the Huacanqui Whirlpool.

From the Pozo to Asna Huacanqui is a mile of relatively straight river, along which the banks are bordered by steep but low hills. This stretch of the river has a swift current, but is free from whirlpools. Between Asna Huacanqui and Huacanqui the valley is more open and several wide tributary ravines enter it. The banks of the river consist of large debris rather than rock outcrops and the river is a series of rapids. Below Huacanqui for over a mile is the narrowest and deepest part of

FIGURE 5.—*Walls of Pongo Sandstone in deepest Part of the Canyon*

the canyon. The walls of the Pongo sandstone, through which the river cuts its course, rise sheer from the water's edge to a height of 1,000 feet. Projecting ledges of the more massive beds deflect the current from side to side and give rise to endless counter-currents and whirlpools and churn the water into large waves. On emerging from the Pongo sandstone, the height and steepness of the walls decrease, and as the river widens its fury diminishes.

GEOLOGY

STRUCTURE

The Pongo de Manseriche is cut almost at right angles to the axis of an asymmetrical anticline that forms the Cordillera Oriental. The oldest formation exposed at the axis of the anticline is the Pongo sandstone.

Successively younger beds are encountered upstream to beyond the mouth of the Santiago River and downstream to beyond Graña. The strike of the axis is about north 20 degrees east and it has a low southerly pitch at the Marañon River.

The west limb of the fold appears to be free of important faulting and a complete succession of beds is exposed from the axis of the anticline to the Santiago River. The steepest dips are encountered in the lowermost beds near the axis, where the angle of dip is 70 degrees or more. Between the Huacanqui Whirlpools the dip flattens from 15 to 20 degrees, but at Asna Huacanqui steepens again from 35 to 40 degrees, which dip is maintained up to the Pozo. Between the Pozo and the Santiago River the dips steepen again, ranging generally between 40 and 60 degrees. The younger Tertiary beds exposed above the Santiago River have a very low dip.

The structure of the eastern limb of the anticline is quite different. The lowest beds exposed at the axis have a moderate dip of less than 20 degrees. Outward from the axis the dip increases uniformly to vertical at the mouth of the Pongo. From that point to nearly 2,000 feet below Puerto Melendez the dip is vertical to steeply overturned to the west. Where the younger Tertiary beds are first encountered they have a steep easterly dip that rapidly decreases downstream to a uniform dip of about 5 degrees. Faulting has greatly interrupted the complete sequence of beds. Part of the Cretaceous Limestone-Shale Series has been cut out. The threefold division of the Red Beds recognizable on the western limb is here not distinquishable and part of the series is cut out by an overthrust fault at the contact with the younger Tertiary.

STRATIGRAPHY

General statement.—Lithologically, four major groups of strata may be recognized along the portion of the Marañon River under consideration. They may be conveniently designated, in ascending sequence, the Pongo sandstone, the Cretaceous Shale-Limestone Series, the Red Beds, and the younger Tertiary. In addition, there is, of course, the Recent alluvium.

The Pongo sandstone.—The lowest formation exposed in the canyon is a light-colored to white, massive to thick-bedded, quartzitic sandstone. Its texture is medium to coarse-grained, with streaks and bands of fine pebbly rock. In many places it is quite porous. Cross-bedding is common. About 1,000 feet of these beds have been cut through by the river without exposing the base of the formation. Small springs of warm

sulphur water emitting the odor of sulphuretted hydrogen issue from these beds.

Cretaceous Shale-Limestone Series.—Overlying the Pongo sandstone and well-exposed on both limbs of the anticline are about 3,500 feet of shale, limestone and sandstone. The greater part of the thickness of the series consists of gray shale with a tendency to nodular fracture. The gray color ranges from light pearl gray to very dark gray or almost black, but the prevailing color is lead gray. Some of the shale is highly calcareous and grades into argillaceous, nodular-fracturing limestone.

Included in this group is considerable limestone. Much of this occurs as many thin strata interbedded with shale; but there are several

FIGURE 6.—*Outcrop of Shale-Limestone Series*
Nodular calcareous shale with intercalations of limestone.

prominent horizons of limestone in more massive beds aggregating 100 to 300 feet in thickness that form escarpment ridges. The limestone ranges from light-gray, pure limestone to dark-gray, slaty rock. Sandstone beds of appreciable thickness are also included in the series. They are most abundant near the top and bottom. The most prominent horizon is near the top of the series and forms the Asna Huacanqui Whirlpool and the mouth of the Pongo. Its lithology is very similar to that of the Pongo sandstone, and it has been called the Huacanqui sandstone.

The Red Beds.—The next younger division of strata are the Red Beds. The top of the series is not exposed on either limb of the anticline. On the east limb the overturned beds are thrust over the younger Tertiary

below Puerto Melendez. At the mouth of the Santiago River they appear to be unconformably overlain by younger beds. A much greater thickness of Red Beds is found on the west limb than on the east limb. On the east limb the thickness is about 4,000 feet and on the west limb double that amount.

The Red Beds on the east limb of the anticline consist of red shale, red sandstone, and a few beds of light tan sandstone, but are not divisible into units on the basis of differences in lithology. On the west limb they are made up of three lithologic units. The lower part of the series, between the Asna Huacanqui Whirlpool and the Pozo, is characterized by the prominence of sandstone. Most of the sandstone is red, but there are

FIGURE 7.—*Shale with Intercalations of thin Beds of Limestone in the Shale-Limestone Series*

horizons of blue-gray and tan-gray rock. Generally, red sandstone and red shale alternate in beds a few feet or less in thickness, and groups of such beds are separated by greater thicknesses of red shale; but there are horizons of thicker-bedded and more massive sandstone with little or no intercalated shale. The massive sandstone is highly cross-bedded. At several horizons calcareous conglomerate is associated with the sandstone. It occurs as bands and streaks of red shale pebbles in a calcareous matrix. Where it attains a thickness of a foot or two it usually includes lenses and streaks of red sandstone. On the outcrops the calcium carbonate dissolves, giving the rock a characteristic pitted surface.

Overlying the sandy Red Beds and outcropping upstream from the Pozo is an intermediate series of softer beds, made up chiefly of gray shale. The lower part of these beds is much better exposed than the upper part; but the low elevation of the terrace, the widening of the river, and the decrease in outcrops indicate the prevailing shaly character of the latter. In the lower part are thin intercalations of calcium carbonate and sandstone. Some of the calcium carbonate is fibrous aragonite. The lead-gray shale has nodular fracture and includes occasional bands of carbonate concretions. In the uper part of this group of beds are horizons of soft, friable, light green-gray to gray-white sandstone of coarse to pebbly texture. One of these is nearly 300 feet thick, but the

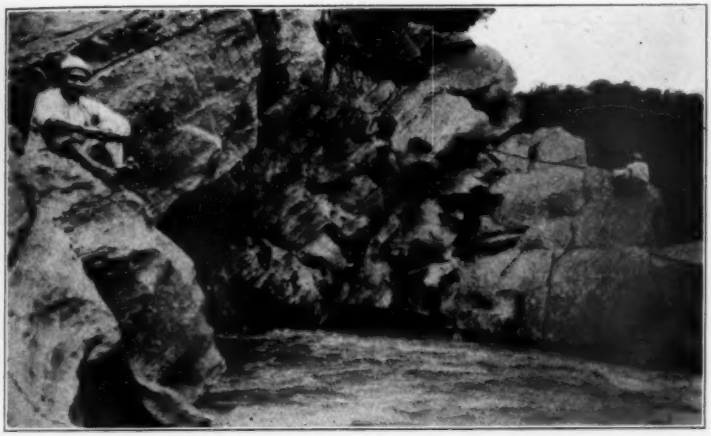

FIGURE 8.—*The Huacanqui Sandstone at the Asna Huacanqui Whirlpool*

rock is so friable that it does not produce a marked topographic expression.

The upper part of the Red Beds consists essentially of red clay-shale with pale-green blotches or zones of green. Beds of soft, argillaceous, fine-grained red sandstone a few feet thick occur at wide intervals.

The lithology of this Red Bed Series is that of typical Red Beds. Its areal extent seems to be very wide. These beds were encountered by Sinclair and Wasson[2] far to the north in Ecuador, on the Napo River, and I have encountered them in other parts of the Peruvian *montaña* far to the south of the Pongo de Manseriche. In 1924, on the Ellsworth

[2] Joseph H. Sinclair and Theron Wasson: Explorations in eastern Ecuador. The Geographical Review, vol. 13, 1923, pp. 190-210.

Expedition, we found them widespread and well exposed in the valley of the Huallaga River to beyond Juanjui. Along that river and elsewhere they include beds of salt and gypsum. At several localities along the Huallaga River we had the novel sight in a wet jungle country of high river bluffs of rock salt.

The younger Tertiary.—Strata younger than the Red Beds are encountered only some distance above and below the Pongo. On both sides of the point between the Marañon and Santiago rivers are outcrops of nearly horizontal, massive, rather soft, tan sandstone. Downstream from Puerto Melendez are beds lithologically distinct from the Red Beds, separated from them by a fault, and characterized by low dips except

FIGURE 9.—*Weathered Surface of Calcareous Conglomerate in Red Beds*

close to the fault. Exposures show thick beds of friable sandstone and clay shale of various colors, but mostly of blue-green color. At least 1,000 feet of these beds are exposed, without showing either the top or the bottom of the series.

CORRELATION

The Pongo sandstone yielded no fossils, but its age is fairly closely determined by its stratigraphic position beneath the Cretaceous Shale-Limestone Series. The oldest known fossils from the latter are of Albian age; consequently the Pongo sandstone is older than Albian. The Ellsworth Expedition found in the high ranges of the Andes fossiliferous

calcareous beds that correspond to the Cretaceous Shale-Limestone Series of the Pongo. Provisional age determinations of the collections from these beds by Mr. Maxwell Knechtel gave them a range as low as Albian. They are underlain by a prominent series of shale with thick horizons of massive quartzitic sandstone in which are intercalated beds of coal. The Pongo sandstone is probably the equivalent of these massive quartzites of the Andes. Their age has been variously placed at the top of the Jurassic and the base of the Cretaceous. Hence the Pongo sandstone is probably of Lower Cretaceous or Neocomian age and may extend into the upper part of the Jurassic.

The Shale-Limestone Series is quite fossiliferous. Most conspicuous are ammonites. The collections that we made also include echinoderms and a variety of pelecypods. They are now being studied by Mr. Maxwell Knechtel. His provisional determinations give them a range from Albian to Coniacian. The age of the Shale-Limestone Series is, therefore, essentially Middle Cretaceous, but extends upward into the Upper Cretaceous or, in other words, ranges from the upper part of the Comanchean to the lower part of the Upper Cretaceous.

Hitherto no fossils had been found in the Red Beds. Because they are younger than the Cretaceous Shale-Limestone Series, they have generally been referred to the Tertiary; but their continuous sequence overlying the Shale-Limestone Series indicate that they are in part at least Upper Cretaceous. As they are older than the younger Tertiary, which is pre-Pliocene, it is quite likely that they do not range as young as the Miocene. Contrary to previous opinion, the Red Beds are not unfossiliferous. Though not abundant, fossils were found in this series of beds at a number of localities throughout the Peruvian *montaña*. They do not include a wide range in forms, nor are they forms of the highest diagnostic value, but it is hoped that their determination will fix still more closely the age of the Red Beds.

The younger Tertiary beds yielded no fossils, so that their age can be determined only as between that of older and younger strata. Outside of the Pongo de Manseriche area is horizontal gray clay shale which includes lignitic coal and brackish water Pliocene fossils. These beds are quite widespread in the Peruvian Amazonian region, and the fossiliferous locality at Pebas has been known for many years. The younger Tertiary Series is older than these Pliocene beds. Within the *Pongo* area, they are nowhere in normal contact with the older Red Beds; hence their Tertiary age is well established, and the probability is that they are Middle Tertiary, possibly Miocene.

Age of the Cordillera Oriental

All of the formations of the Pongo de Manseriche area were involved in the orogenic movements that gave rise to the folding and uplift of this portion of the eastern range of the Andes. Thus those movements were subsequent to the deposition of the Younger Tertiary Series, the age of which is probably Miocene. The fossiliferous Pliocene beds that are found in adjoining portions of the Amazon region were seen only in horizontal position close to the present level of the river, and have been subjected, therefore, to no movement, other than a small amount of uplift, since their deposition. These data fix the age of the Cordillera Oriental with reasonable assurance as late Miocene.

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POSSIBLE POST-CRETACEOUS FAULTING IN THE APPALACHIANS[1]

BY GEORGE W. STOSE

(Presented before Section E, American Association for the Advancement of Science, December 30, 1926)

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GENERAL STATEMENT

In the study of the physiography of the Appalachians, uplift and tilting of the peneplains toward the sea have been generally recognized and differential uplift resulting in folding of the erosion surfaces has been postulated by some, but, so far as the writer recalls, no one has postulated faulting of these peneplains. The writer has had opportunity to study the physiography of a large part of the Appalachians, supplemented by a study of topographic maps, and some general conclusions on the peneplains of part of Virginia and detailed physiographic descriptions of local areas in Pennsylvania, New Jersey, Maryland, and West Virginia have been published.[2]

CORRELATION OF PENEPLAINS

In these physiographic studies a series of peneplains has been observed in the Piedmont province and another series in the Blue Ridge and Appalachian ridges, but correlation of the two series of erosion surfaces

[1] Manuscript received by the Secretary of the Society February 7, 1927.
Published with the permission of the Director, U. S. Geological Survey.

[2] Jour. Geol., vol. xii, 1904, pp. 473-484. Folios 170 and 179 of the Geol. Atlas, U. S. Geol. Survey, 1909 and 1912, and other unpublished folios; text on back of Delaware Water Gap Topog. Map, 1916; Bulls. XVII and XXIII, Va. Geol. Survey, 1919 and 1922.

has been made with difficulty and considerable doubt is cast on many of the correlations that have been made. In the Mercersburg-Chambersburg, Pennsylvania, folio by the writer, published in 1909, the highest peneplain on the tops of Cambrian and Silurian quartzite ridges of South Mountain and North Mountain, of supposed early Cretaceous age, was called the Schooley, following the application of this name by W. M. Davis and M. R. Campbell. In a later study of the Delaware Water Gap region, Pennsylvania and New Jersey, the writer found that the peneplain on Schooley Mountain and other high ridges of the Piedmont province was distinctly lower than the level of the peneplain on the top of Kittatinny Mountain, and the two were described in the report on that area in 1916 as distinct. The higher, or Kittatinny, peneplain was regarded as possibly earliest Cretaceous, and the lower, or Schooley, peneplain as possibly middle or late Cretaceous. No representative of the Kittatinny Plain was recognized in the Piedmont province, although rocks of about the hardness and resistance of those of Kittatinny Mountain compose some of the mountains of the Piedmont. The Schooley peneplain was tentatively correlated with a lower partial plain developed at about the same level on somewhat less resistant rocks in the Blue Ridge province, called the Weverton peneplain.

In a detailed study for folio publication of the Fairfield and Gettysburg quadrangles, Pennsylvania, which lie to the east of the Chambersburg quadrangle and extend from the Blue Ridge province into the Piedmont province, conditions similar to those in the Delaware Water Gap region were observed. The upper peneplain on the tops of North Mountain and South Mountain, recognized as the Kittatinny, has an altitude of 2,000 feet. The highest erosion surface on the Piedmont ridges of the region, developed on the Cambrian quartzites of the Pigeon Hills, is at 1,040 feet elevation, above which rise peaks to 1,240 feet, which may be residuals of a somewhat higher peneplain, possibly 1,400 feet. There is no evidence of a peneplain in this part of the Piedmont which in any way approximates the Kittatinny level on South Mountain.

Projected profiles of the upland adjacent to the Potomac and Susquehanna and of interstream areas show similar discordance in altitude between the peneplain on the tops of the Appalachian ridges and the highest peaks or erosion surface on the Piedmont ridges. F. Bascom and E. B. Knopf,[3] in their physiographic studies in southeastern Pennsylvania, also found no remnants of the Kittatinny peneplain in the Piedmont.

[3] F. Bascom: Jour. Geol., vol. xxix, 1921, pp. 540-559.
E. B. Knopf: Bull. Geol. Soc. Am., vol. 35, 1924, pp. 636-666.

The absence of remnants of the Kittatinny peneplain in the Piedmont is usually explained as due to the entire obliteration of that surface by the erosion which formed the later and lower Schooley peneplain. Con-

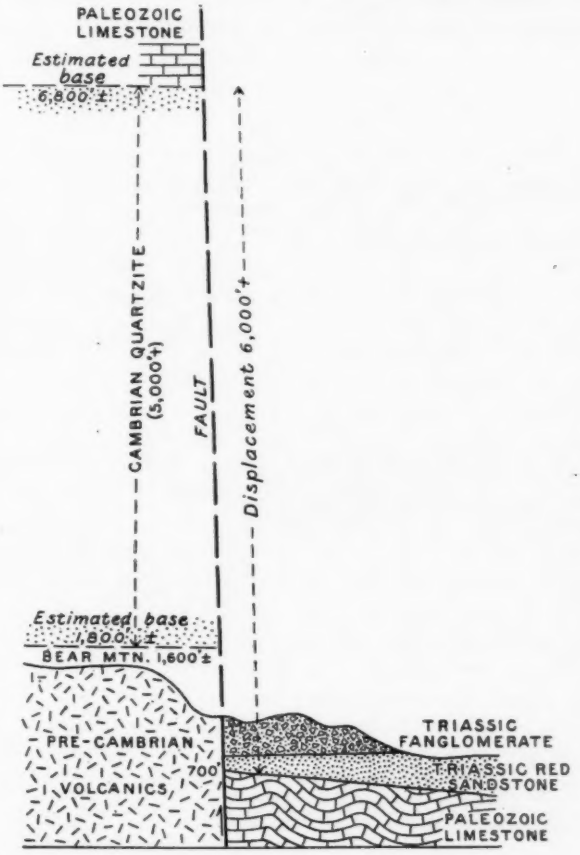

FIGURE 1.—*Displacement on Triassic bounding Fault*

This diagrammatic section shows a displacement of at least 6,000 feet along Triassic bounding fault. Difference in altitude of estimated former base of limestone on top of South Mountain and surface of limestone at foot of mountain. Altitude of base of limestone beneath Triassic not known.

siderable weight is given to this argument by the fact that the Piedmont does not carry such massive and resistant quartzites as some of the Cam-

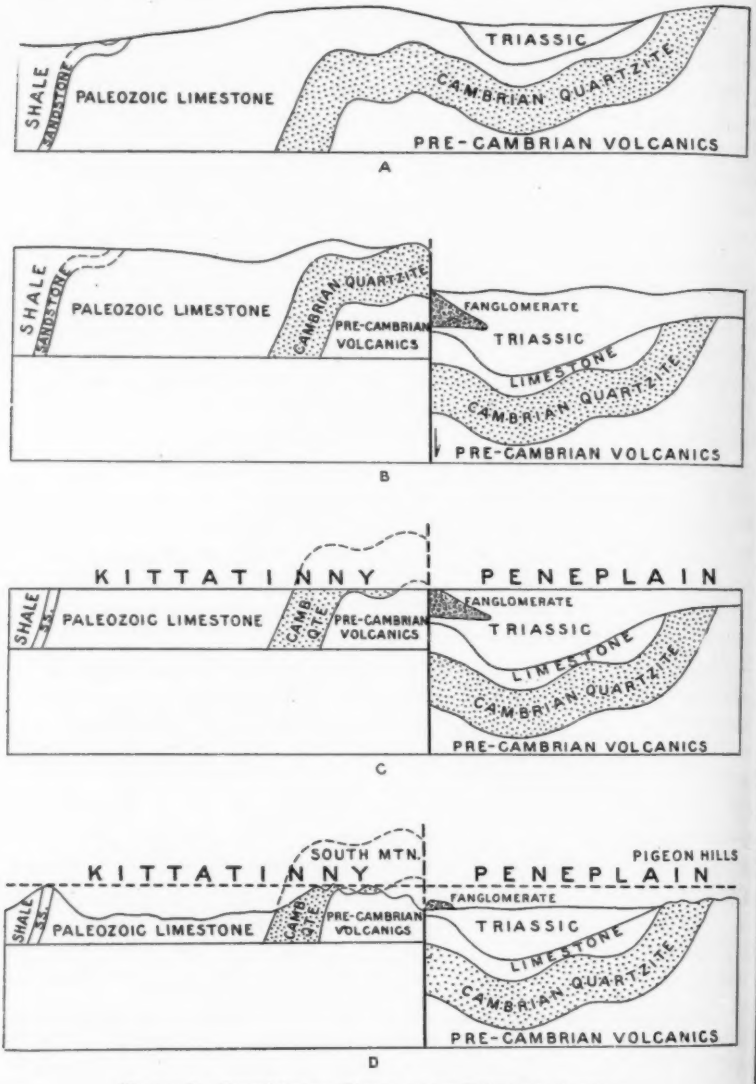

FIGURE 2.—*Peneplains on Theory of pre-Kittatinny Faulting*

The diagrammatic sections show successive steps under the theory that all the faulting preceded peneplanation.

A. Deposition of Triassic sediments in basin.

B. Faulting and formation of fanglomerate at foot of uplifted South Mountain mass and filling of basin to peneplain level.

C. Peneplanation.

D. Erosion removing all remnants of the peneplain in the Piedmont.

brian and Silurian quartzites of the Appalachian ridges. However, the fairly thick, resistant Cambrian quartzites of Sugarloaf in Maryland and of the Pigeon Hills and Hellam Hills in southern Pennsylvania, and some of the granitic rocks and hard siliceous gneisses and schists of the Piedmont province, are believed to be sufficiently resistant to have preserved some remnants of such a surface if one existed.

Possible faulting of Peneplains

A possible different explanation of the discrepancy in altitude of the highest peneplain on the Appalachian ridges and that in the Piedmont was suggested in the study of Triassic rocks at the southeast foot of South Mountain in southern Pennsylvania. It has been fully established there that the Triassic rocks have been faulted down relative to the older rocks adjacent on the west by normal faults along the mountain front. The total vertical displacement west of Gettysburg has been determined to be at least 6,000 feet (see figure 1). Movement on this fault began near the close of Triassic sedimentation, for the last Triassic deposits that were laid down and are still preserved are of coarse fanglomerates the material of which is largely unassorted quartzite and limestone fragments derived by erosion from adjacent escarpments and steep rocky gorges in the recently uplifted South Mountain mass. Further uplift of this mass by faulting occurred after the close of the Triassic, for quartzite and limestone that formerly capped it have been entirely removed by erosion from the mountain top, and the fanglomerates are themselves downfaulted. If the full amount of this faulting took place before the Kittatinny peneplain was formed, the basin must have been filled with Triassic sediments at least 800 feet above the fanglomerate—that is, to the level of the tops of the present quartzite ridges, about 1,900 feet above sea, which is the level of the peneplanation; for in the formation of the Kittatinny peneplain, when more than 5,000 feet of Cambrian quartzite and limestone were worn off of South Mountain and the whole land surface was reduced to a gently sloping plain, this surface extended across the Triassic area to the sea (see figure 2).

The Triassic fanglomerate hills at the foot of South Mountain closely resemble in form Tertiary alluvial cones in other parts of the Appalachians and appear to have been little changed by erosion since their formation, but in reality they are remnants of a large alluvial cone cut through and dissected by the streams which at present issue from the mountains (see figure 3). There is, however, no evidence or reason to

believe that the fanglomerate was covered by 800 feet or more of later Triassic sediments, reaching to the level of the tops of the present mountain ridges, which is the level of the Kittatinny peneplain (see figure 4). So far as one can judge from the beds present, the fanglomerate marks the closing stage of Triassic sedimentation, not only in the Gettysburg region, but in many other parts of the basin. The question, therefore, arises, may not its position so much below the Kittatinny peneplain level be due in part to faulting?

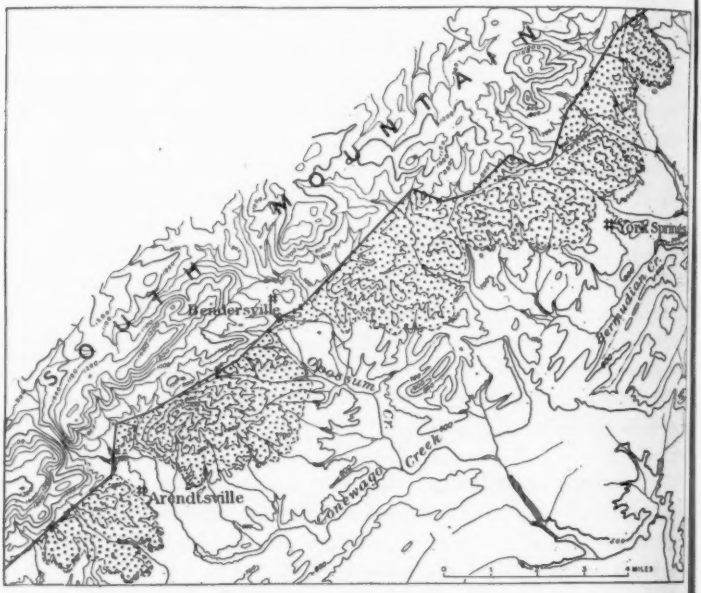

FIGURE 3.—*Distribution and Form of Triassic Fanglomerate and Relation to the uplifted South Mountain Fault Block*

Fanglomerate shown by dotted pattern. Heavy line, fault.

That there has been great recurrent movement along the old Triassic boundary fault since Triassic time is established by the fact that the fanglomerate, which was deposited at the close of the Triassic period, terminates abruptly along the fault and was undoubtedly displaced by it. There is, however, no evidence that all this movement took place at one time; in fact, it is more reasonable to believe that movement recurred along this old fault at intervals from the close of Triassic time possibly

to the present, for recent mild earthquakes in the region are generally ascribed to slight movement on Triassic fault-planes.

Statement of Fault Theory

The following hypothesis is therefore offered, not as one that has been thoroughly tested and proven, but as one that must be considered as a possible explanation of existing relations. Part of the displacement on the Triassic boundary fault took place after Kittatinny peneplanation, the western part of the peneplain having been relatively uplifted several hundred feet (see figure 5), the sequence of events having been about as follows: Just before the close of the Triassic period the South Mountain mass was somewhat uplifted by movement along the fault that bounds the Triassic basin, and at its foot a fanglomerate was formed,

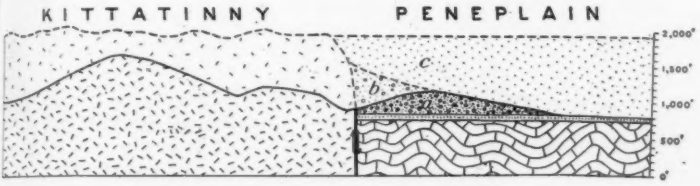

FIGURE 4.—*Hypothetical Filling of Triassic Basin*

The sketch section shows amount of filling necessary if peneplain has not been faulted. (*a*) Latest known Triassic deposit, the fanglomerate, at the foot of South Mountain; (*b*) the possible former extent of the fanglomerate; (*c*) the filling of the Triassic basin with Triassic sediment after the formation of the fanglomerate, made necessary if the peneplain was formed at the present level of the mountain tops and since eroded.

which merged eastward into soft red sediments that were being deposited ir the basin, but the basin filling did not reach much higher than the tops of the present fanglomerate hills. After the close of Triassic deposition the South Mountain mass was further uplifted by renewed movement of the old fault-plane; prolonged erosion under stable land conditions reduced the area to a peneplain, wearing down the resistant rocks of South Mountain, the Pigeon and Hellam Hills, and the Piedmont upland to the level of the present ridge tops and eroding the soft Triassic rocks to the same level; recurrent movement along the old Triassic bounding fault uplifted that part of the peneplain west of the fault to the present Kittatinny level, leaving the part east of the fault at the present Schooley level, approximately 500 feet lower.

The effect of this hypothesis on the correlation of peneplains is shown in the profiles on figures 6 and 7.

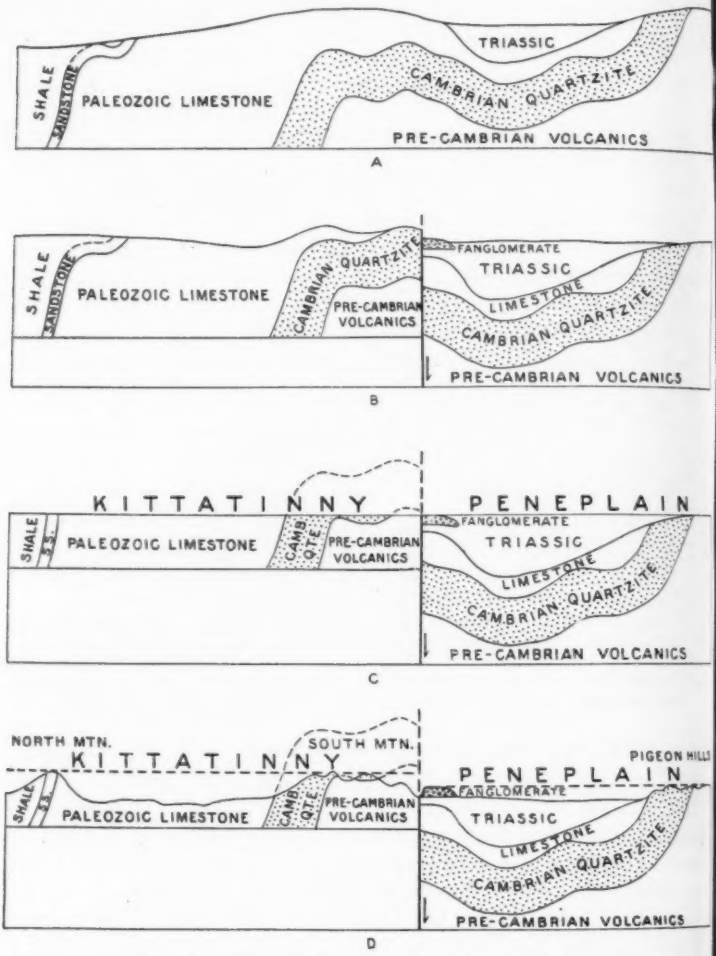

FIGURE 5.—*Peneplains on Theory of post-Kittatinny Faulting*

These diagrammatic sections show successive steps under the theory that there has been faulting since peneplanation.

A. Deposition of Triassic sediments in basin.

B. Faulting and formation of fanglomerate at foot of uplifted South Mountain.

C. Further uplift of the South Mountain mass and peneplanation.

D. Renewed uplift and faulting of peneplain and later erosion. The Kittatinny peneplain on North and South mountains is shown as faulted down to the level of the peneplain on the Piedmont hills.

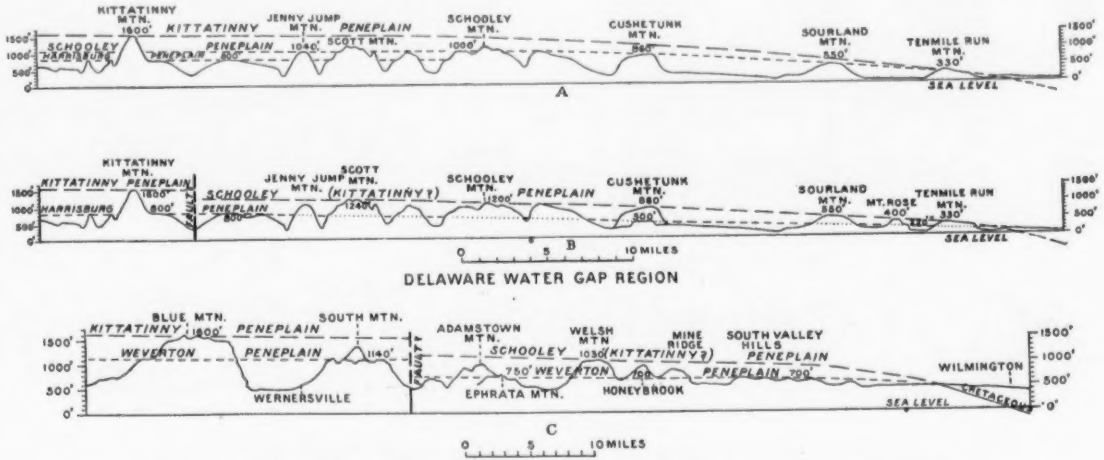

FIGURE 6.—*Comparison of Sections with and without hypothetical post-Cretaceous Faulting*

The profiles show the effect of hypothetical post-Cretaceous faulting on correlation of peneplains.

A. Delaware Water Gap region, without faulting.

B. Delaware Water Gap region, with faulting.

C. Projected profile through Wernersville and Wilmington, with faulting.

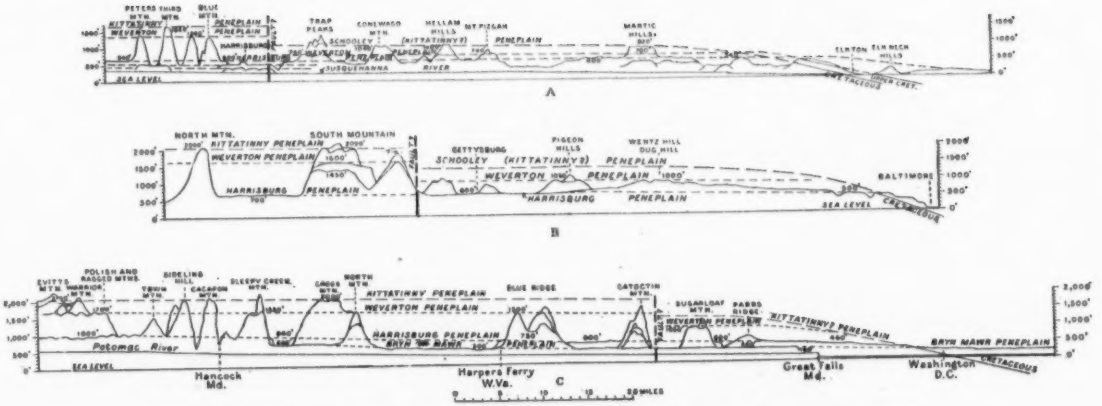

FIGURE 7.—*Correlation of Peneplains under the Hypothesis of post-Cretaceous Faulting*

The profiles show the effect of hypothetical post-Cretaceous faulting on correlation of peneplains.

A. Projected profile along Susquehanna River.

B. Projected profile through Gettysburg and Baltimore.

C. Projected profile along Potomac River.

The Highlands in the Delaware Water Gap region, on the mountains of which the Schooley peneplain is so well preserved and from one of which it takes its name, is in the Blue Ridge province and lies west of the basin in which the Triassic rocks are preserved, and therefore west of the Triassic bounding fault in this area. However, in this region, the rocks of the Great Valley are similarly faulted by normal faults with downthrow to the southeast, and some of the postulated post-Cretaceous movement must have taken place on one of these planes, as the Schooley peneplain in the Highlands was faulted down with the Triassic.

A study of the various profiles shows that the Weverton peneplain, next below the Kittatinny and of supposed later Cretaceous age, also seems to have been faulted down along the Triassic bounding fault, whereas the still lower Harrisburg peneplain, of supposed Eocene age, is not affected by the fault. The postulated faulting of the peneplains occurred, therefore, in the interval between Weverton time and Harrisburg time. The exact age of these peneplains can not be regarded as established, and it is not the purpose of this paper to discuss that problem, but, tentatively adopting the ages generally assigned to them, the postulated faulting took place at or near the close of the Cretaceous.

RÉSUMÉ

By this hypothesis the Schooley peneplain in the Piedmont is correlated with the Kittatinny peneplain in the Blue Ridge province and Appalachian ridges, the difference in altitude between the two parts of the peneplain being accounted for by post-Cretaceous normal faulting. The Weverton peneplain in the Blue Ridge province and Appalachian ridges, about 300 feet lower than the Kittatinny, instead of being correlated with the Schooley peneplain in the Piedmont, as heretofore, is correlated with a lower peneplain, probably F. Bascom's Honeybrook peneplain, whose lower altitude in the Piedmont is due also to downfaulting. The Mine Ridge peneplain of E. B. Knopf, represented by the level top of Mine Ridge and by wind gaps at 1,100 to 1,200 feet in the Appalachian ridges, is tentatively correlated with the Kittatinny (Schooley).

The suggested possible correlation of peneplains and their altitudes are given in the following table.

Approximate Levels of Peneplains under th

Section	Northwest of Fault		Post-Cretaceous fault
	KITTATINNY (SCHOOLEY)		
			Feet
Delaware Water Gap region		Kittatinny Mountain 1,600 feet	360
Through Wernersville and Wilmington	Blue Mountain 1,600 feet	South Mountain 1,500 ± (1,340+) feet	400
Susquehanna River	Third Mountain 1,640 feet		500
Through Gettysburg and Baltimore	North Mountain 2,060 feet	South Mountain 2,000 feet	500
Potomac River	Cross Mountain 2,000 feet	Catoctin Mountain 1,850 ± (1,700+) feet	450
	WEVERTON		
Through Wernersville and Wilmington	Blue Mountain and Wind Gaps 1,100–1,180 feet	South Mountain 1,140 feet	400
Susquehanna River	Second Mountain 1,360 feet		450
Through Gettysburg and Baltimore		South Mountain 1,600 feet	500
Potomac River	Polish Mountain 1,700 feet	Sleepy Creek Mountain 1,650 feet / Blue Ridge 1,500 feet	450
	HARRISBURG		
Delaware Water Gap region		Above Water Gap 800 feet	0
Susquehanna River	Above Peters Mountain 640 feet	Harrisburg 600 feet	0
Through Gettysburg and Baltimore		Newville 700 feet	0
Potomac River	Above Paw Paw 1,000 feet / Hancock 950 feet	Martinsburg 800 feet / Harpers Ferry 560 feet	0

Approximate Levels of Peneplains under the

Northwest of Fault			Post-Cretaceous fault	
KITTATINNY (SCHOOLEY)				
	Kittatinny Mountain 1,600 feet		*Feet* 360	
Blue Mountain 1,600 feet	South Mountain 1,500 ± (1,340+) feet		400	
Third Mountain 1,640 feet			500	
North Mountain 2,060 feet	South Mountain 2,000 feet		500	
Cross Mountain 2,000 feet	Catoctin Mountain 1,850 ± (1,700+) feet		450	
WEVERTON				
Blue Mountain and Wind Gaps 1,100–1,180 feet	South Mountain 1,140 feet		400	
Second Mountain 1,360 feet			450	
	South Mountain 1,600 feet		500	
Polish Mountain 1,700 feet	Sleepy Creek Mountain 1,650 feet	Blue Ridge 1,500 feet	450	
HARRISBURG				
	Above Water Gap 800 feet		0	
Above Peters Mountain 640 feet	Harrisburg 600 feet		0	
	Newville 700 feet		0	
Above Paw Paw 1,000 feet	Hancock 950 feet	Martinsburg 800 feet	Harpers Ferry 560 feet	0

aceous t	Southeast of Fault				
	PENEPLAIN				
	Scott Mountain 1,240 feet	Schooley Mountain 1,200 feet	Cushetunk Mountain 860 feet	Sourland Mountain 550 feet	Tenmile Run Mountain 330 feet
	Adamstown Mountain 1,200 ± (1,000+) feet	Welsh Mountain 1,030 feet	Barren Hill 960 feet	Mine Ridge 860-900 feet	
		Conewago Hills 1,040 feet	Hellam Hills 1,000 feet	Martic Hills 920 feet	
		Pigeon Hills 1,400 ± (1,240+) feet			
	Sugarloaf 1,400 ± (1,250+) feet				
	PENEPLAIN				
	Ephrata Mountain 750 feet	Honeybrook 740 feet	Mine Ridge 700 feet	South Valley Hills 700 feet	
	Elizabethtown 850 ± (740+) feet	Mount Pisgah 740 feet	Martic Hills 700 feet		
	Arendtsville Hills 1,100 feet	Pigeon Hills 1,050 feet	Dug and Wentz Hills 1,000 feet		
	Sugarloaf 1,050 feet		Parrs Ridge 860 feet		
	PENEPLAIN				
	Below Water Gap 800 feet	Near Cushetunk Mountain 500 feet	Near Mount Rose 220 feet		
	Above Martic Hills 600 feet	Below Martic Hills 540 feet			
	Gettysburg 600 feet	Above Baltimore 500 feet			
	Below Blue Ridge 560 feet	Washington 460 feet			

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ORDOVICIAN SHALE AND ASSOCIATED LAVA IN SOUTHEASTERN PENNSYLVANIA[1]

BY GEORGE W. STOSE AND ANNA I. JONAS

(*Presented before the Society December 28, 1926*)

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[1] Manuscript received by the Secretary of the Society April 5, 1927.
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General Relations[2]

Ordovician shale forms a broad belt, about 10 miles wide, across the southeastern part of Pennsylvania, from Greencastle on the southwest to Belvidere, New Jersey, on the northeast. It lies northwest of the Great Valley, a limestone valley locally called Cumberland Valley, southwest of Susquehanna River, and Lebanon, Reading, and Allentown valleys, successively to the northeast. The name Martinsburg has been applied to the shale throughout this belt. A rather large area, 17 miles long, which is connected with the main belt at Hummelstown, extends southwest to Shepherdstown and is referred to as the Steelton area. Many small areas of Ordovician shale occur southeast of the main belt, most of which lie north of the Triassic basin. They are shown on the map, figure 1, and will be described under the following names: Schaefferstown, Shillington, Wyomissing, Oley Valley, Limeport, Jutland, Doylestown, and Cocalico shale areas. The shale in the vicinity of Jonestown, in the main belt, is described in detail because of its significant stratigraphic relations.

Southeast Border of the Main Shale Belt

SOUTHWEST OF SUSQUEHANNA RIVER

The Martinsburg shale southwest of the Susquehanna closely resembles in character and relations the shale of the type locality at Martinsburg, West Virginia. It is a dark-gray to bluish-black shale ranging in age from Trenton to Eden. Its lower beds contain graptolites, trilobites, and brachiopods of lower Trenton age. It rests conformably on limestone probably of latest Black River age. The following section[3] shows the characteristics of the shale and of the underlying rocks in the area southwest of Susquehanna River.

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[2] The field observations in the Great Valley west of Reading, on which the conclusions for that part of the area are largely based, were made by the senior writer.

[3] G. W. Stose: Mercersburg-Chambersburg Folio (no. 170), Geol. Atlas U. S., U. S. Geol. Survey, 1909, slightly modified from later information by E. O. Ulrich by removal of thin shaly limestone of Trenton age from the Chambersburg.

Composite Section in the Mercersburg-Chambersburg Area, Pennsylvania

Martinsburg shale, 2,000 feet.	Chiefly dark-gray shale; upper part dark-gray, crumbly shale, bleaches whitish and weathers to whitish clay, and some soft greenish arkose, which contain Eden fossils; black carbonaceous fissile to blocky shale and thin shaly limestone carrying *Cryptolithus* (*Trinucleus*) and *Sinuites* (lower Trenton) fauna at base.
Chambersburg limestone, 100-750 feet.	Shaly limestone and black carbonaceous limestone at top (*Christiania* and upper *Nidulites* zone, upper Black River age); dark nodular, platy, and massive limestone (*Nidulites* zone, Black River age); pure fine-grained dove (Lowville) and crystalline fossiliferous limestone (Black River and upper Chazy age).
Stones River limestone, 675-1,050 feet.	Chiefly very pure, even-grained, fine-grained dove limestone, some magnesian limestone near the base and thin black chert in the middle; of Chazy age.
Beekmantown limestone, 2,300 feet.	Thick-bedded blue, dove, and pink limestone and interbedded gray magnesian limestone, with several layers of nodular chert.
Conococheague limestone, 1,600 feet.	Blue and gray limestone banded by siliceous impurities which weather to ribbed rock and shaly fragments, with purer beds containing *Saukia*, *Calvinella*, *Cryptozoon*, and other fossils assigned by Ulrich to his lower Ozarkian.

Not all the divisions of the Chambersburg limestone are everywhere recognizable, the Christiania zone being absent in places. The general conformable relation of the Martinsburg shale and underlying Chambersburg limestone extends nearly, if not quite, to the Susquehanna. On Conodoguinet Creek, 4 miles west of the river, Martinsburg shale rests on one of the upper divisions of the Chambersburg. In the lower part of the shale are thin fossiliferous limestones and calcareous arkosic layers which weather to a characteristic porous, rusty arkosic sandstone observed at other places in the main belt and in many of the other areas of shale. The fossils in the limestone have been identified by E. O. Ulrich as *Premitia bivertex, P.* cf. *ulrichi* and *unicornis, Dalmanella* (small sp.), *Leptobolus* cf. *lepis, Ctenobolbina* sp., and have been referred by him to the upper Trenton. The Martinsburg shale and Chambersburg limestone in the Pennsylvania Railroad cut at the west side of the river, opposite Harrisburg, are much disturbed, somewhat faulted, and

FIGURE 1.—*Outline Map of Southeastern Pennsylvania*

Showing Ordovician shale areas referred to in this paper. The southeastern border of the main shale area, which crosses the State, and all smaller areas are shaded.

badly crushed at their contact. No fossils have been found there and the age of the particular beds present has not been determined.

HARRISBURG TO HUMMELSTOWN

The Chambersburg limestone has not been observed east of the Susquehanna. East of Harrisburg the shale at most places is in contact with blue limestone and magnesian limestone of Beekmantown type, which, at Rutherford, contains Beekmantown fossils in the uppermost beds. The pure Stones River limestone and "cement rock" (Leesport limestone, described later), which normally overlie the Beekmantown to the east and outcrop in this relation on the south side of the valley 2 miles west of Rutherford, are absent along the contact in this part of the main shale belt. The presence of a hard, ferruginous quartzite and highly sheared slate in places along the shale-limestone contact suggests that the observed surface relations of these formations from Harrisburg to Hummelstown is due to faulting and does not represent the normal sequence. If that is the case, it is probable that from Harrisburg to Hummelstown the limestone of the valley has been overthrust northwestward against the shale.

HUMMELSTOWN TO WOMELSDORF

Thin limestone containing impure layers that weather to porous arkosic sandstone like that on Conodoguinet Creek is interbedded near the base of the Martinsburg shale and shown in the railroad cut just west of Hummelstown. The uppermost beds of the limestones which underlie the Martinsburg shale in this area are generally thin bedded, dark, slaty, and impure limestone, which contains poorly preserved fossil shells and crinoid stems of probable lower Trenton age. It is extensively quarried as "cement rock" to the east, at Schlemville, north of Reading. In this report it is named Leesport limestone, from Leesport, on Schuylkill River, where it is best exposed. The Leesport limestone in this area forms a belt of variable width, probably due to irregular thickness of sedimentation. It is underlain by a considerable thickness of very pure, white, sugary marble and fine-grained blue limestone, which are believed to be of Stones River age because of their stratigraphic position, but in which determinable fossils have been found at but few places. A gastropod identified as *Maclurea magna* and a cephalopod, probably of Stones River age, have been found in this pure limestone at Womelsdorf, and other fossils of probable Stones River age occur at Paxtang, but Ulrich is not fully convinced that the beds are not pure limestone in the Beekmantown. Fossiliferous Beekmantown limestone underlies this pure limestone. The

high-calcium limestone of supposed Stones River age occurs in a narrow, continuous band from Hummelstown nearly to Lebanon, its outcrop being very sinuous, due to folding. Many quarries are opened along its attenuated outcrop. The following section of the Leesport limestone was measured northwest of Lebanon:

Section of Leesport Limestone ("Cement Rock") in Cut of the Lebanon and Trenton Branch, Philadelphia and Reading Railroad, Northwest of Lebanon

		Feet
Martinsburg shale.	Dark, fissile shale.	
Leesport limestone ("cement rock")	Thin-bedded, light-gray limestone, with wavy, hard slaty partings, weathering ribbed	30
	Thick-bedded, blue limestone, full of round, glassy grains, which weathers to porous sandstone	6
	Thin-bedded, fine-grain, ribbed limestone, with hard slaty partings one-half to one inch apart, and some interbedded shale	45

In the area from Lebanon east to Womelsdorf both the thin-bedded, dark, argillaceous Leesport limestone ("cement rock") and the Stones River limestone underlie the shale in apparent conformity. These formations vary in width of outcrop, with a maximum at Myerstown, where the "cement rock" is 2 miles wide. Although the Leesport limestone is known to have a variable thickness, the unusual width of outcrop is due in part to low dips and gentle folding. The underlying pure limestone is also gently folded and similarly has a variable width of outcrop. The Stones River limestone ends abruptly at Womelsdorf and has not been found to the northeast in Pennsylvania.

WOMELSDORF TO SCHUYLKILL RIVER

The shale lies adjacent to Beekmantown limestone from Womelsdorf east and northeast to Schuylkill River, except just west of Wernersville, where there is a wide belt of intervening thin-bedded Leesport limestone which carries crinoid stems and other fossil fragments, of probable lower Trenton age. It is believed that the irregular relations of these formations between Womelsdorf and Wernersville are the result of thrust-faulting and not of overlap, the Beekmantown limestone apparently being thrust over Martinsburg shale and Leesport limestone. The fault continues some distance east of Wernersville, where the Conococheague and Beekmantown limestones are thrust northward over a narrow belt of shale. Northeast of Wernersville to the Schuylkill River the Martinsburg shale of the main belt rests on Beekmantown limestone in apparent unconformity due to overlap.

NORTH OF READING

The Leesport limestone varies greatly in thickness and distribution northwest and north of Reading. At Schlemville the thin-bedded dark "cement rock" has been extensively quarried, but a mile to the east and west these beds pinch out rapidly. The "cement rock" and the pure limestone of probable Stones River age are both absent throughout most of this district, and the Martinsburg shale rests unconformably on thick-bedded pure blue and magnesian gray limestone of the Beekmantown. Another indication of unconformity is the presence of a heavy conglomerate near the base of the Martinsburg shale capping a small hill 2 miles south of Leesport.

Northwest of Leesport, on the Schuylkill River, several lenticular areas of thin-bedded argillaceous limestone occur within the shale area. These are anticlines of the underlying Leesport limestone exposed by the erosion of the shale. This argillaceous limestone disintegrates to soil so rapidly that good exposures are rarely seen, and its character and thickness are difficult to determine. The fresh exposures on the Schuylkill at Leesport give such a good section of these rocks that the formation is named from that place. At Leesport the formation comprises over 100 feet of thin-bedded limestone with dark slaty partings and some interbedded shale, the section being as follows:

Section of the Rocks at Leesport, Pennsylvania

		Feet
Dark shale (Martinsburg).		
Leesport limestone ("cement rock")	Thick-bedded calcareous sandstone	20
	Shale in 1- to 3-inch beds, with interbedded thin blue limestone in 1-inch beds; thicker conglomerate beds at top	50±
	Thin-bedded limestone with quartz grains and shale partings	20±
	Thick-bedded, bluish, calcareous quartzite	10
	Thin-bedded limestone with shale partings	30±
Dolomite (Beekmantown).		

In the old quarry east of Schlemville, 5 miles northeast of Leesport, the quarry rock comprises a solid mass 25 feet thick of thin-bedded dark limestone which directly underlies the shale.

NORTH OF ALLENTOWN

Northwest of Catasauqua the Martinsburg shale rests on thin-bedded siliceous-banded limestone, which is the "cement rock" of this region. At Egypt trilobites were collected by the writers from these "cement beds" not 20 feet below the Martinsburg shale, and were identified by

E. O. Ulrich as of the genus *Leiostigium*, referred by him to his upper Ozarkian. The limestone which carries the fossils resembles the siliceous-banded limestone in the upper part of the Conococheague limestone of the Mercersburg-Chambersburg area, but the latter contains trilobites of the genus *Calvinella* which Ulrich refers to his lower Ozarkian, and therefore is older than the limestone with *Leiostigium* at Egypt. Purer limestone containing species of *Cryptozoon* referred by Ulrich to his lower Ozarkian occurs several hundred feet lower in the section southeast of Egypt. The *Cryptozoon*-bearing beds of the area have been called Allentown limestone in reports, but the fossiliferous siliceous-banded limestone that lies above, which have been referred by Ulrich to his upper Ozarkian, have not been heretofore observed. The section in the vicinity of Egypt measured by the writers is as follows:

Section in Vicinity of Egypt, Pennsylvania

	Feet
Gray shale (Martinsburg).	
Fossiliferous crystalline limestone interbedded with dolomite and shaly argillaceous limestone; contains *Leiostigium* sp. and gastropods, referred by Ulrich to his upper Ozarkian	20
Concealed	40±
Shaly to platy limestone, crystalline limestone, and cellular chert containing *Leiostigium*	10
Concealed	30±
Shaly, impure, sheared limestone containing *Leiostigium*	10
Concealed	20
Dark, glistening dolomite	10
Light-gray and dark-gray fine-grained dolomite in alternating layers	150±
Concealed	?
Pure light-blue limestone containing *Cryptozoon, undulatum*, referred by Ulrich to his lower Ozarkian	?

The Beekmantown limestone, although present in the Lehigh Valley, is absent at Egypt and probably elsewhere in this vicinity, and the Martinsburg shale rests unconformably on the eroded surface of the *Leiostigium* zone of the Ozarkian of Ulrich and in places, as north of Seemsville, on the *Cryptozoon*-bearing limestone of the lower Ozarkian of Ulrich.

West and southwest of Allentown the "cement rock" is very irregular in width of outcrop.[4] It is not known whether this "cement rock" is of the type of that at Egypt and of the same age, or is Leesport limestone of probable lower Trenton age, but its irregularity in occurrence and absence in places indicates extensive overlap of the Martinsburg shale if

[4] T. N. Dale: Manuscript map of Slatington Quadrangle. U. S. Geol. Survey.

the "cement rock" in that locality is Trenton and greater overlap if it is Ozarkian of Ulrich, as it is in the vicinity of Egypt.

North of Seemsville several small lenticular areas of limestone exposed within the shale area have been interpreted by Miller[5] and Behre[6] as limestone lenses interbedded in the Martinsburg shale, although the limestone is described by Behre as containing *Cryptozoons*. Neither of the writers of this report has visited the limestone inliers, but they are of the opinion that relations there are similar to those at Egypt, 5 miles to the west, and that the *Cryptozoon*-bearing limestone is the one locally called Allentown exposed in anticlines unconformably beneath the Martinsburg shale. E. O. Ulrich[7] and Arthur Keith,[7] who have seen these limestone inliers, also hold this view. The unconformity under this interpretation is even greater here than at Egypt.

At Nazareth, northeast of Allentown, the Martinsburg shale is underlain by "cement rock," beneath which is a pure limestone, and beneath that the Beekmantown limestone. B. L. Miller in an earlier report[8] on the area used the names Nazareth limestone, Nisky limestone, and Coplay limestone respectively for the "cement rock," the underlying pure limestone, and the Beekmantown limestone, adopting the names given in an earlier report by Wherry.[9] In the same year Peck[10] applied the name Nazareth to the pure limestone above the Beekmantown and gave the name Lehigh limestone to the "cement rock."

In a subsequent report[11] Miller states that the Beekmantown limestone at Nazareth is overlain by 200 feet of light to dark-gray, coarsely crystalline, pure fossiliferous limestone of Black River age, which he calls the cement limestone, and this grades up into dark argillaceous limestone or "cement rock" of Trenton age, 200 to 300 feet thick. The "cement rock" grades up into the main mass of the Martinsburg shale, and is itself so impure that in weathered outcrops it would be classed as a shale if the fresh rock were not exposed in the quarry.

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[5] B. L. Miller: Allentown Quadrangle no. 206, Atlas of Pennsylvania. Pennsylvania Geological Survey, 1925, pp. 24-27.

[6] J. C. Behre, Jr.: Observations on structure in the shales of Northampton County, Pennsylvania. Jour. of Geol., vol. xxxiv, no. 6, 1926, p. 486: Slate in Northampton County, Pennsylvania. Pa. Geol. Survey, Bull M9, 1927, pp. 21-23.

[7] Personal communication.

[8] B. L. Miller: Mineral pigments of Pennsylvania. Top. and Geol. Surv. Com. of Pa., Rept. 4, 1911, pp. 15-19.

[9] E. T. Wherry: The early Paleozoics of the Lehigh Valley District, Pa. Science, new ser., vol. 30, 1909, p. 416.

[10] F. B. Peck: Lehigh Portland Cement District, Pa. Top. and Geol. Com. of Pa., Rept. 5, 1911, pp. 24-38.

[11] B. L. Miller: Allentown Quadrangle (no. 206), Atlas of Pa. Pa. Geol. Surv., 1925, pp. 102-112.

The "cement rock" called Nazareth limestone by Miller does not occur at Egypt and has not been traced west of Allentown, so that neither its exact extent nor whether it is equivalent to the "cement rock" of probable lower Trenton age here called Leesport limestone, is known. The extension of the name Nazareth to the "cement rock" of the belt west of Allentown does not seem warranted, therefore, and the new name Leesport limestone has been introduced.

Fossils collected from the "cement rock" at the Nazareth quarry by E. O. Ulrich[12] have been identified by him as *Mesotrypa* cf. *regularis, M.* cf. *quebecensis, Rhinidictya fidelis, Dinorthis pectinella,* and *Rafinesquina alternata,* which are assigned by him to very lowest Trenton.

NORTH OF EASTON

The Martinsburg shale seems to be conformable on the Jacksonburg limestone of Trenton and Black River age in the eastern part of the State and adjoining parts of New Jersey. In the vicinity of Jacksonburg, New Jersey, the formation is described by Kümmel[13] as comprising two divisions, the lower one, dark-blue to black fossiliferous limestone and calcareous shale containing fossils of Black River age, about 50 feet thick; the upper one, dark-blue highly fossiliferous limestone of lower Trenton age, about 100 feet thick, the middle 30 feet of which is more shaly than the rest. The dark limestone grades upward into the Martinsburg shale, which at Branchville, New Jersey, is reported by Stuart Weller[14] to contain *Diplograptus foliaceous, D. angustifolius, Lasiograptus mucronatus, Corynoides calycularis,* and *Dalmanella testudinaria.* These are referred by Ulrich to the lower Trenton.

Areas Southeast of the main Belt

STEELTON AREA

This area of shale, nowhere more than 2 miles wide, extends southwest from the main belt at Hummelstown across Susquehanna River at Steelton to Shepherdstown, a distance of 17 miles. The shale is surrounded by limestone, except at its northeastern end. When the senior author first studied it at its southwest end he regarded the shale as probably Lower Cambrian, Waynesboro, because, like the Waynesboro, it contains some purplish red shale and thin calcareous rusty sandstone. Later in 1920, some poorly preserved graptolites were found in the shale at Steelton and were identified by Ulrich as probably of Normanskill type

[12] Personal communication.
[13] H. B. Kümmel : U. S. Geol. Survey. Geol. Atlas, Raritan Folio, no. 191, 1914.
[14] Report on Paleontology. Geol. Survey of New Jersey, vol. III, 1903, p. 52.

and the shale was considered to be of upper Chazy age. Recently the senior author has studied the Steelton belt in greater detail and has reached another conclusion as to the age of the shale.

The shale occupies a closely compressed, sharply overturned syncline, and on the south side is much crushed and sheared, and injected by numerous quartz veins. The overturned dip and shearing is shown in a contact of the shale and limestone in the southern part of Steelton and in the sheared slaty limestone quarried at Bowmansdale.

The shale, which is chiefly dark gray to buff, has a zone of hard purplish red and green shale and arkosic sandstone near its base which

FIGURE 2.—*Martinsburg Shale Unconformable on Limestone*

The shale is unconformable to bedding of underlying limestone, probably Beekmantown, at Pennsylvania Railroad cut 2 miles west of Hummelstown

makes conspicuous outcrops along the north border of the shale from its eastern end nearly to Susquehanna River. The apparent absence of these beds along the south border of the syncline is probably due to the crushed condition of the shale on this limb of the fold and the consequent greater weathering of the shale.

In the greater part of the Steelton area Beekmantown limestone forms the nearest limestone outcrop to the shale and apparently directly underlies it, but thin-bedded slaty limestone of the Leesport limestone lies beneath the shale in places. South of Paxtang the Leesport limestone lies beneath the shale and is underlain by pure limestone of Stones River type. In a quarry this limestone contains *Leperditia, Girvanella,* a large

Maclurea-like gastropod, and other fossils of probable Stones River age. The limestone and dolomite, which apparently lie on the shale in the southern part of Steelton, but which are overturned and really underlie it stratigraphically, are apparently of Beekmantown age, but the uppermost layers contain fragments of Bryozoa and shells of probable lower Trenton age. Three miles to the east, the shaly limestone beneath the shale has greater thickness and contains crinoid stems, the bryozoan *Eridotrypa,* and the brachiopod *Dalmanella,* of probable lower Trenton age. In the railroad cut 2 miles west of Hummelstown the shale rests with marked unconformity on limestone of probable Beekmantown age (figure 2), and in the hill just to the southeast it overlies pure limestone of Stones River type and has a limestone conglomerate at its base.

Since the shale of the Steelton area overlies Leesport limestone, which is of probable lower Trenton age, the graptolites collected from the shale at Steelton and other places in this area are now regarded by Ulrich[15] as probably Trenton or younger, and not Normanskill, and the shale is therefore Martinsburg. The irregular distribution of the underlying limestones is due to unconformity by overlap of the shale, as is shown in the railroad cut 2 miles west of Hummelstown (figure 2).

SCHAEFFERSTOWN AREA

An area of shale 3 miles long forms prominent hills between Schaefferstown and Kleinfeltersville, just west of South Mountain (Lebanon-Berks counties) and north of the hills composed of Triassic rocks. Beds of hard purple and green shale and blocky sandstone occur along the northern edge of the shale near the base of the formation and are comparable in lithology and stratigraphic position to similar beds previously described in the Steelton area. The Martinsburg shale overlies unconformably the Conococheague and Elbrook limestones. A normal fault separates both shale and limestones, as well as older rocks of South Mountain, from the Triassic rocks to the south, which lie in a dropped fault-block.

SHILLINGTON AREA

There are two areas of shale near Shillington, east of South Mountain and north of the Triassic rocks. The shale of the western area is infolded in a syncline which is cut off on the south by a thrust-fault by which Lower Cambrian and pre-Cambrian rocks of South Mountain (Lebanon-Berks counties) have been thrust northward over the valley rocks. The eastern area lies in an eastward extension of the same syn-

[15] Personal communication.

cline, and the shale caps a small steep-sided hill which is cut off abruptly at the northeast by a normal fault. In both these areas the shale lies unconformably on Elbrook limestone (Middle Cambrian), the oldest formation of the region on which it has been found to rest.

WYOMISSING AREA

This narrow shale area, which extends from Wernersville through Sinking Springs and Wyomissing to Frush Valley north of Reading, has already been mentioned in the description of the southern margin of the main belt from Womelsdorf to Wernersville, where it was stated that this narrow shale area lies north of a thrust-fault which has been traced southeast from Womelsdorf. From Wernersville to Sinking Springs the shale occurs in a narrow belt of hills, more or less detached, because the overthrust fault has cut out the shale in places. North of Wernersville and in the shale hill just to the east, the dark slaty Leesport limestone underlies the shale in normal relation on its north side. To the eastward the shale overlaps on its north side onto Beekmantown limestone, and east of the Schuylkill River it rests by unconformity on Conococheague limestone. At Frush Valley it ends abruptly against an east-west normal fault. Wherry,[16] as the result of his work on the Paleozoic rocks of the Reading Quadrangle, interpreted this irregular relation of the shale to the limestones on the north side of the belt as due to faulting. The writers consider that this narrow shale band is a closely folded syncline of Martinsburg shale, which on its north side overlaps toward the east unconformably on Beekmantown and Conococheague limestones but on its south side is faulted. That the relations on the northern side are those of sedimentary deposition and overlap is well shown in the quarry of the Glengarry Brick and Shale Company at Wyomissing, the section of which is as follows:

		Feet
Martinsburg shale	Dark-gray to buff shale with some hard, shiny, purple beds	?
	Hard shale with several beds of white sandstone with coarse quartz grains and small pebbles, weathering rusty	15
	Dark shale, folded and poorly exposed	50±
Dolomite and limestone, probably Beekmantown.		

The southern boundary of the shale is apparently a fault along which Beekmantown and Conococheague limestones have been thrust north-

[16] E. T. Wherry: Manuscript map of Paleozoic rocks of the Reading Quadrangle. U. S. Geol. Survey, 1915.

westward against the shale, and west of Sinking Springs entirely conceal the shale in places.

FIGURE 3.—*Unconformity at Base of Martinsburg Shale*

The shale is markedly unconformable to underlying limestone (locally called Allentown) in south-facing wall of quarry at Limeport (see sketch, figure 3).

OLEY VALLEY AREA

East of Reading, between the Reading Hills and the Boyertown Hills and north of the Triassic red rocks, is the somewhat circular Oley Valley

underlain by limestone and shale. This valley is part of a block which has been faulted down and tilted northwestward, preserving a considerable area of Ordovician shale which overlies the limestone in a syncline on the northwest side of the down-faulted block, next to the bounding normal fault. The shale is the characteristic dark-gray to blue-black fissile shale, which weathers buff. At Friedensburg it is faulted against pre-Cambrian granite by the post-Triassic fault which forms the west boundary of the shale for 4 miles. On the north and east sides the shale is

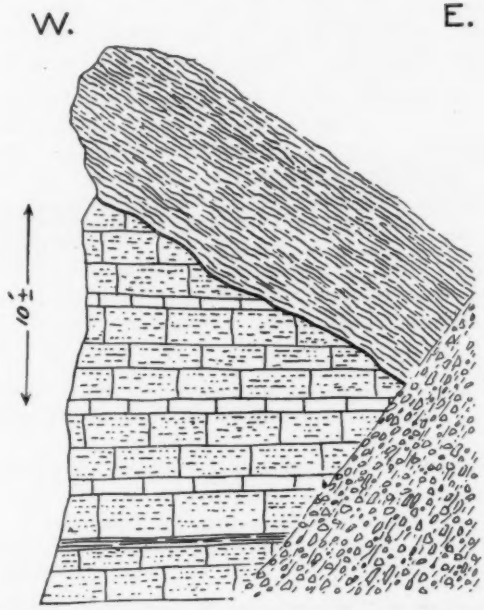

FIGURE 4.—*Unconformable Relations of Martinsburg Shale and underlying Limestone*
The limestone is locally called Allentown. The view is sketched from south-facing wall of quarry at Limeport (see figure 3).

surrounded by a narrow band of thin-bedded, slaty, dark Leesport limestone ("cement rock"), which is underlain by a pure blue limestone and crackled dolomite of Beekmantown age containing black chert. A narrow, irregular area of slaty, thin-bedded Leesport limestone and Martinsburg shale, apparently occupying a shallow syncline, extends 3 miles southeastward from the shale area, nearly to Yellow House. A small mass of Ordovician shale at Earlville, 1 mile east of Yellow House, is

preserved in a narrow down-faulted block. Another small shale mass 2 miles northeast of Friedensburg is similarly a down-dropped block between two faults.

There is apparently no unconformity at the base of the shale in Oley Valley, it being underlain everywhere by the Leesport limestone of probable lower Trenton age, but there is an unconformity between the Leesport and the underlying Beekmantown limestone.

LIMEPORT AREA

A small mass of Ordovician shale, less than one-fourth mile long, rests on limestone in a narrow, straight valley 7 miles south of Allen-

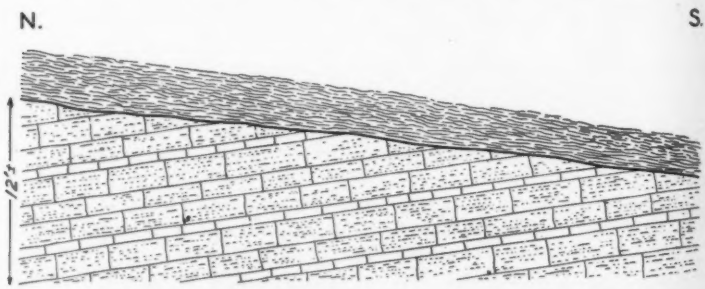

FIGURE 5.—*Unconformable Relations of Martinsburg Shale and underlying Limestone*
The view is sketched from west-facing wall of quarry at Limeport.

town. This narrow valley is apparently a dropped block or graben of limestone between walls of pre-Cambrian granite and Lower Cambrian quartzite. The gray shale is badly crushed and sheared to a rust-stained, shiny slate. In the walls of a quarry at Limeport the shale may be seen lying diagonally across the beveled edges of the underlying light and dark-gray limestone and dolomite which have been called Allentown limestone in reports and which contain *Cryptozoon* assigned by Ulrich to his lower Ozarkian. The relation is clearly one of unconformity of the Martinsburg shale on Allentown limestone. (See figures 3, 4, and 5.) This area was probably referred to by F. F. Hintze[17] in describing Martinsburg shale in isolated masses resting on older rocks from the Hardyston quartzite to rocks of Trenton age.

[17] Abstract, Bull. Geol. Soc. America, vol. 29, 1918, pp. 94, 95.

JUTLAND AREA

At Jutland, New Jersey, 15 miles southeast of Easton, Pennsylvania, and 5 miles east of the Pennsylvania State line, there is an area of Ordovician shale about 2 miles square which, because of its lithologic character and fossils, should be mentioned in this discussion of the Ordovician shale of Pennsylvania. The Martinsburg shale is described in the Raritan Folio,[18] which includes the Jutland area, as a black shale with some red shale in the lower part and calcareous sandstone above. Graptolites and other fossils of Trenton age occur in the main belt of the Martinsburg shale at Branchville, New Jersey, 40 miles north of Jutland, but in the Jutland area four species of graptolites were identified by Ruedemann that are characteristic of the Normanskill shale, which Ulrich assigns to the upper Chazy. These forms are *Climacograptus phyllophorus* (Gurley), *Dicranograptus ramosus* (Hall), *Cœnograptus gracilis* (Hall), and *Reteograptus geinitzianus* (Hall). The Martinsburg shale in the Raritan Folio area overlies the Jacksonburg limestone, which contains fossils of lower Trenton and Black River age, and although the fauna reported from the shale in the Jutlnd area was considered of upper Chazy age, this shale was mapped in the folio as also underlain by Jacksonburg limestone. If the shale at Jutland contains an upper Chazy fauna as reported, it can not overlie Jacksonburg limestone of Trenton age, as shown on the geologic map in the folio, and it can not be Martinsburg but must be an older shale, and a new name should be applied to it.

DOYLESTOWN AREA

A small area of shale, believed to be Martinsburg, is associated with the limestone west of Buckingham Mountain 3 miles east of Doylestown. This area of Paleozoic and pre-Cambrian rocks is about 10 miles long and is entirely surrounded by Triassic rocks. It is in general strike with the Cocalico shale area, next to be described, which lies north of Lancaster Valley. The shale and limestone have been exposed by the erosion of their cover of Triassic rocks after uplift of the block along a normal fault on the southeast side of the area. The rock is dark-gray, green, and purple, fissile, shiny shale with thin porous, rusty, arkosic sandstone and quartzite beds, similar to the Martinsburg shale of the Schaefferstown and other areas. The limestone in the valley is chiefly Conococheague (Allentown of local reports), but Elbrook and Beekmantown limestones are believed also to be represented. No fossils were found in the shale,

[18] U. S. Geol. Survey, Folio No. 191, 1911.

which occurs at the southwest end of the limestone valley. The shale lies across the trend of the limestones in what appears to be a fault relation, but in view of the unconformable relation of the Martinsburg shale to underlying limestones elsewhere in the region, this discordance may likewise be due to unconformity.

COCALICO SHALE AREA

A large area of Ordovician shale lies south of the belt of Triassic rocks and north of Lancaster Valley. This shale, called Cocalico by the writers,[19] extends in a continuous belt from Rheems to Ephrata, and detached areas of the shale extend 8 miles farther east, a total of 30 miles. It has its maximum width of 5 miles west of Manheim. East of Manheim it divides into two narrower belts. The northern one follows the south side of the Triassic rocks to Denver, where it ends by being overlapped by those beds; the southern belt extends to Ephrata, and a long narrow band with several detached areas beyond reach nearly to Terre Hill. This belt is also closely associated with Triassic rocks, which are faulted down with the shale south of Ephrata in a narrow dropped block or "graben." The Cocalico shale overlies Beekmantown limestone in most of this area, but many of the shale boundaries are faults.

The Cocalico shale is a bluish black to gray fissile shale with beds of fine yellowish green, arkosic sandstone containing many clear glassy quartz grains, most plentiful near the base of the formation. In many places, also near the base, are beds of hard purple and green shale. These shales are more abundant in the northern part of the belt, where they are associated with rust-stained and greenish white, hard, vitreous, fine-grained sandstone composed of glassy quartz grains and containing a few specks of sedimentary mica. This sandstone, with overlying purple and green shale, is well exposed, apparently in a closely compressed anticline, in the valley of Chickies Creek at Whiteoak, where it forms a ridge that extends 3 miles westward. Another belt of purple and green shale and sandstone branches off southwestward and extends to the end of the shale area, where it is covered by Triassic sediments. A third belt of sandstone and purple and green shale forms a parallel ridge to the south and extends eastward past Penryn, trending toward an anticline to the east that brings the underlying limestone to the surface at Hammer Creek. The hard sandstone occurs only in the northern part of the shale area, and the purple and green shales are best developed and apparently thicker where

[19] G. W. Stose and A. I. Jonas: Lower Paleozoic section of southeastern Pennsylvania. Wash. Acad. Sci. Jour., vol. 12, no. 15, 1922, p. 365.

associated with the sandstone, but they occur at several places on the southern border of the shale near its base—northwest of Manheim, north of Diston, at Kissel Hill, west of Sporting Hill, and northwest of Terre Hill.

Graptolites were first found by the writers in the shale at Kisse Hill and northeast of Oregon in 1921; others were found in the shale east of Denver in 1923. At that time they were considered by Ulrich to be of Normanskill type and the shale to be probably of Chazy age. As the shale was believed to be older than Trenton, the name Martinsburg was not applicable and a new name, Cocalico, was given by the writers.[20] Further study by Ulrich of these poorly preserved graptolites and those from the Steelton area has thrown doubt on their earlier identification, and he is now inclined to believe that they are younger than Chazy and probably early Trenton in age. In that case the Cocalico shale may be equivalent to the Martinsburg shale of the main belt and of the Steelton area, and if the equivalency is established the name Cocalico should be abandoned.

The lithology of the Cocalico shale and of the Martinsburg shale east of Harrisburg is strikingly similar. The hard purple and green shales, porous arkosic sandstone, and hard rust-stained to greenish indurated sandstone which occur near the base of the shale in the northern part of the Cocalico belt are very similar to beds near the base of the Martinsburg shale in the eastern part of the Steelton area, the Schaefferstown area, the Doylestown area, and especially in the Jonestown area, yet to be described. The purplish and green shales near Old Line and Penn are spotted with shiny, light-green blebs and contain small, angular fragments of quartz, which suggest that they had a tuffaceous origin. Specimens from near Penn show under the microscope angular fragments of granulated quartz in a ferruginous clay matrix. Although they are much less crystalline than spotted slates of known volcanic origin in the western Piedmont region of Maryland, which are either sheared amygdaloid or tuff, they bear a marked resemblance in color and other characters to these volcanic rocks. As will be discussed later, lava flows occur at the base of the Martinsburg shale in the Jonestown area north of Lebanon. The occurrence of probably volcanic material in the Cocalico shale is additional evidence of the equivalence in age of the Cocalico and Martinsburg shales.

The limestone which underlies the Cocalico shale in most places resembles the Beekmantown in lithologic character and its uppermost beds

[20] Idem.

contain upper Beekmantown fossils. The fossils identified by Ulrich were the ostracod *Isochilina seelyi* (Whitfield) and species of *Lophospira* and *Eccyliopterus* from south of Manheim, *Maclurites oceanus* (Billings) from south of Sporting Hill, and crinoid segments and *Turritoma* sp. from a quarry west of Brownstown. A younger fauna, probably of early Trenton or Black River age, is suggested by *Strophomena* sp., *Prœtus* sp., and segments of crinoid stems from a locality north of Brunnerville; also by a collection from dark-blue argillaceous limestone, like the Leesport, that underlies the shale northeast of Denver, which contains bryozoa fragments, an orthoid brachiopod referred to *Dalmanella, Plectambonites* sp., and a specimen of an *Amphyx*-like trilobite. Cystid plates and columns from shaly limestone beneath the shale north of Mount Joy are considered by Ulrich to be upper Chazy, closely related to forms in the Conestoga limestone.

Fossil evidence therefore shows that the basal part of the Cocalico shale is probably of lower Trenton age and that it lies in places on limestone of lower Trenton or Black River age, and it is therefore unconformable to the Beekmantown limestone, which it overlies in the greater part of the area. The unconformity is not so markedly noticeble in this area as it is in the region north of the belt of Triassic rocks, where some of the overlapped formations come and go irregularly at the limestone-shale contact. The unconformity may lie below the shaly limestones which contain lower Trenton or older fossils and which may represent the initial part of the shale deposition.

CONESTOGA LIMESTONE

The Conestoga limestone is a thin-bedded, blue, argillaceous limestone which extends from northeast of Philadelphia westward along the Chester and Quarryville valleys, north to Lancaster, and across the Lancaster, York, and Hanover valleys to the Maryland line. Similar limestone of about the same age occurs also in small valleys south of the main valley belt from Susquehanna River southwest into Maryland, where it has been named Frederick limestone.

It has been suggested by the writers[21] that the Cocalico shale is the northern representative of the Conestoga limestone. The Cocalico shale occurs only north of, and the Conestoga limestone only south of, the axis of uplift represented by the Honeybrook-Welsh Mountain upland and the Chestnut, Chickies, Hellam, and Pigeon Hills. The Frederick limestone of Maryland, the approximate equivalent of the Conestoga limestone, lies

[21] G. W. Stose and A. I. Jonas: Ordovician overlap in the Piedmont province of Pennsylvania and Maryland. Bull. Geol. Soc. America, vol. 34, 1923, p. 520.

south and southeast of Catoctin Mountain, which may be regarded as the southwest extension of this uplift but separated from it by down-faulted Triassic rocks.

North of Lancaster the Conestoga limestone and Cocalico shale are only about 5 miles apart across the strike, and the uplift which separates them is structurally low at this point and broken by Triassic faulting. The suggestion of the probable equivalence of the shale and the argillaceous limestone was a natural one, in view of the fact that both were considered to be of Chazy age. Few fossils have been found in the Conestoga or in the Frederick limestone. Only one determinable species, *Strophomena stosei*, has been found in the Conestoga limestone. This form is found also in the Frederick limestone, together with *Acidaspis ulrichi*, *Triarthus* sp., and new species of *Reterocrinus ?*, *Cameroceras*, and *Isotelus*. This fauna, according to Bassler,[22] suggests Chazy or early Black River age, more probably Chazy. These two formations have been tentatively assigned to the Chazy on the basis of these fossils, although none of the species are known to occur elsewhere in the Appalachian Valley, and it is recognized that the correlation with Chazy is only approximate. Ulrich is inclined to favor Black River age on diastrophic grounds, and, furthermore, he has recently identified from the Frederick limestone *Beatricea* cf. *gracilis* and *Bumastus* sp. of probable Lowville age.

The Conestoga and Frederick limestones lie unconformably on the beveled edges of formations from Beekmantown limestone to Harpers schist, of Lower Cambrian age, and therefore were deposited after a period of post-Beekmantown uplift and erosion.[23] The erosion which preceded the deposition of the Martinsburg and Cocalico shales north of the Honeybrook-Hellam Hills-Pigeon Hills axis of uplift took place in post-Beekmantown and pre-Trenton time. Therefore, if the fossils from the Conestoga and Frederick limestones are correctly interpreted as Chazy, those formations are not only older than the Cocalico and Martinsburg shales, but their deposition followed an erosion period which occurred earlier than that which preceded the deposition of the Martinsburg in the north. It is possible that the uplift represented by the Honeybrook, Hellam Hills, and Pigeon Hills anticlines acted as a partial barrier between the two basins in which is apparently recorded such a different erosional and depositional post-Beekmantown history. On the other hand, it may be that the tentative assignment of the Conestoga and Frederick limestones to the Chazy is incorrect, and that they are of later

[22] R. S. Bassler: Cambrian and Ordovician. Maryland Geological Survey, 1919, p. 117.
[23] G. W. Stose and A. I. Jonas: Idem.

age and in part at least equivalent to the Martinsburg and Cocalico shales. If this is the case, the erosion period south of the supposed barrier as well as north of it occurred in post-Chazy and pre-lower Trenton time—that is, during Black River time.

Jonestown Area

Sequence of beds

This area is part of the main shale belt, but deserves special treatment because of the character of the sediments, the presence of interbedded lava, and the intricate block faulting. As previously stated in the description of the southeast border of the main shale belt, Martinsburg shale of the main area at Lebanon rests on 80 feet of thin-bedded, dark, argillaceous limestone and interbedded shale of the Leesport limestone. The sequence, in descending order, with approximate thickness of the lower beds of the Martinsburg shale just north of Lebanon, shown in figure 6, is as follows:

FIGURE 6.—*Generalized Section from Jonestown to Lebanon*

Showing sequence and general structure of beds in the Martinsburg shale and relations of the basaltic lava-flow.

Martinsburg shale—*gs*, black to gray shale; *ws*, white sandstone, with purple and green shale in places; *rys*, red and yellow shale and greenish arkosic sandstone; *bs*, basaltic lava-flow at base of Martinsburg shale; *Ol*, Leesport limestone; *Ob*, Beekmantown limestone; *db*, intrusive diabase.

Composite Section of lower Part of Martinsburg shale North of Lebanon, Pennsylvania

	Feet
Soft red and yellow shale and sandstone interbedded with numerous thin, greenish, crumbly, arkosic grits and thick, harder reddish gray, pebbly, arkosic sandstone	500±
Gray shale	60±
Hard, purplish red shale, green platy to blocky shale, hard arkosic sandstone weathering porous, and hard white quartzose sandstone or quartzite weathering rusty	30±
Dark-gray to bluish-black shale, with thin purplish red shale near base in places	100±
Thin-bedded limestone with black argillaceous partings, a thick bed of sandy limestone weathering to sandstone, and interbedded shale (Leesport limestone)	?

The dark-gray to bluish black shale is of the same character as that of the Martinsburg elsewhere. The zone of hard purplish shale and green platy shale with sandstones is similar to that described in the Schaefferstown and Steelton areas and in the Cocalico shale area north of Lancaster Valley. On Quittapahilla Creek 3 miles northwest of Annville and at Union Water Works 3 miles north of Annville purple and green shales directly overlie thin-bedded, dark, siliceous limestone containing quartz grains, which is the Leesport limestone, where the following section was measured:

Section on Quittapahilla Creek Northwest of Annville

		Feet
	Purple and green shale	10±
Leesport limestone ("cement rock")	Thin-bedded dark limestone with quartz grains and some dark shale	15±
	Thick-bedded calcareous quartzite	6
	Dark thin-bedded limestone and shale	10±

The upper member of this part of the Martinsburg shale, composed of red and yellow shale with interbedded green, crumbly, arkose grits and thick, red, feldspathic, micaceous pebbly sandstone, is so different from the general character of the Martinsburg shale and so closely duplicates beds in the Triassic of the region south of Lebanon that they were at first mistaken for Triassic by the writers and so described in a paper before the Geological Society of America[24] in December, 1924. The red shales of this division of the Martinsburg are dull red and crumble to small particles instead of to fissile leaves and plates, as does most of the Martinsburg shale. The arkosic beds are greenish yellow or brownish red with conspicuous grains of glassy quartz, white kaolinized feldspar, and numerous flakes of black mica. Most of the sandstones on weathering crumble to yellow micaceous sand, but some beds are hard, well-bedded, reddish gray sandstone which was quarried for masonry work in the construction of locks on the abandoned Union Canal northwest of Lebanon. From the intimate relation of these red shales and arkosic sandstones with the dark-gray shales known to be Martinsburg and the prevalence of such rocks over a wide area to the north and northeast, it is concluded that they are part of the Martinsburg formation deposited under somewhat different conditions from that of most of the Martinsburg to the southwest.

The repetition of members of the Martinsburg shale between Lebanon and Jonestown indicates folding. The front line of hills is a syncline

[24] Bull. Geol. Soc. America, vol. 36, 1925, pp. 160-161.

which carries chiefly the dark-gray to bluish-black shale of the lower member, but in its deeper part, north of Cleona and Annville, includes the purple and green shale and hard sandstone of the second member. An anticlinal valley north of this syncline brings the Leesport limestone to the surface, but it has few exposures. The red and yellow shales and arkosic sandstone of the upper member covers most of the region between this valley and Bunker Hills, but black shale outcrops at the surface, presumably in an anticline, 3 miles north of Lebanon.

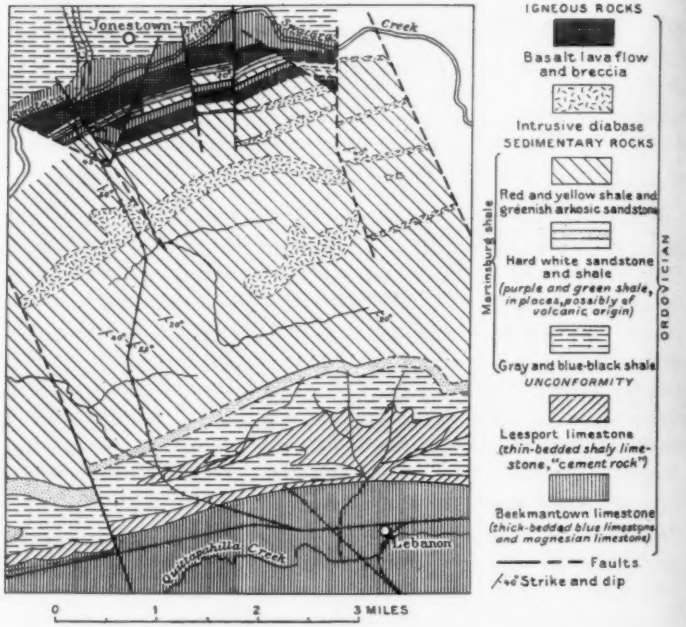

FIGURE 7.—*Geologic Map of the Jonestown-Lebanon Region*

Showing outcrop of Ordovician basaltic lava-flow and divisions of the Martinsburg shale.

South of Jonestown the limestone which underlies the shale is exposed in an anticline in the valley of Little Swatara Creek and on Swatara Creek near their junction. This limestone is thick-bedded, blue to black crystalline and gray magnesian, and is probably Beekmantown. The Leesport limestone is not present. A basaltic lava-flow about 300 feet thick rests on the limestone and is overlain by soft red shale and a thick, massive bed of indurated rust-stained white sandstone, locally a quartzite.

Bedding is not clearly preserved in the quartzite, but its thickness is estimated to be about 60 feet. It is so resistant that it makes the crest of the main ridge of Bunker Hill, and the offsetting of this hard bed by traverse faults furnishes the chief clue to the faulted structure shown on the map (figure 7). Although this rock is hard and firm at the surface, it crumbles to grains in quarry pits and is extensively quarried for building sand. Fossils have not been found in the sandstone nor in the associated shales above the basalt, so that the age of the lava-flow can not be positively determined; but the white sandstone is apparently at the same horizon as a similar sandstone associated with the purple and green shales of the second member of the Martinsburg formation exposed at Quittapahilla Creek, 6 miles southwest, and at the border of the shale area north of Lebanon, and at many other places to the west and southwest.

BASALTIC LAVA

This lava-sheet was first described by Samuel G. Gordon in a paper entitled "Ordovician basalts and quartz diabase in Lebanon County,

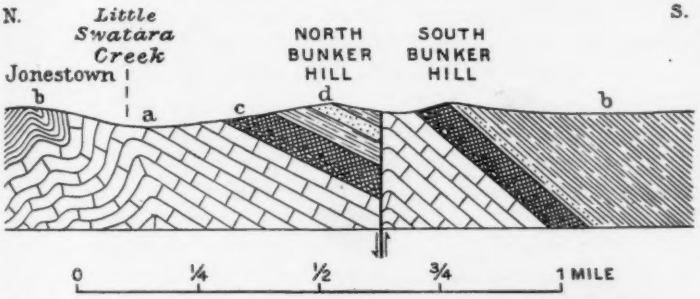

FIGURE 8.—*Detailed Section of the Basaltic Lava-flow at Jonestown, Pennsylvania.*

The lava flowed out on the weathered surface of Ordovician limestone and engulfed fragments of limestone in its basal part. Its outcrop is repeated by a strike-fault.

a. Ordovician limestone.

b. Martinsburg shale.

c. Basaltic lava-flow with breccia of limestone fragments at base.

d. Hard white sandstone in Martinsburg shale, possibly hardened by secondary deposition of silica adjacent to fault.

Pennsylvania."[25] He described two basalt lava-flows and several dikes, or sheets, of intrusive diabase which he shows on the map that accompanies his paper. The disjointed appearance of the dikes and sheets on Gordon's map at once suggests faulting, and a field study of the

[25] Acad. Nat. Sci., Philadelphia, Proc., vol. 72, 1921, pp. 354-357.

area by the writers has made it evident that numerous dip-faults cut across the beds and offset them. The offsetting of hard sandstone which composes the northern ridge of the Bunker Hills is a clear example of such faulting (see figure 7). From the general sequence and relations of the beds inclosing the lava-sheet and the relation of the lava to the limestone floor, as described in detail below, the writers have concluded that there is but a single lava-sheet which is repeated by a strike-fault (see figures 6 and 8).

The lava is an amygdaloidal basalt, the amygdules being filled mostly with calcite, which at the surface is in large part dissolved, leaving a dark, vesicular mass. Some of the amygdules are composed of a reddish mineral which is probably vesuvianite.

The diabase which occurs south of the basalt flow is a quartz diabase[26] of fine to medium grain, composed of labradorite which is zoizitized and augite more or less altered to chlorite, some individuals being completely chloritized. Pyrite is abundant. This saussuritization and chloritization is evident in the hand specimen, for the diabase is dull and greenish black and differs markedly from Triassic diabase in which the feldspar is always clear and sparkling and in which the green color caused by chloritization of the augite is absent. This alteration is further evidence of the greater age of the diabase south of Jonestown. It closely resembles altered pre-Cambrian diabase which occurs in the pre-Cambrian gneisses of the Reading and Boyertown Hills.[27] This diabase also is dull and greenish in color and is characterized by saussuritization of the feldspar and chloritization of the augite. Pyrite is an abundant accessory constituent in it also.

The relation of the lava sheet to the inclosing rocks is best displayed along the Jonestown-Lebanon Road where it crosses the southern ridge of the Bunker Hills. Coarse volcanic breccia of baked and altered limestone fragments in a glassy matrix occurs at the base of the flow and rests on a floor of unaltered thin-bedded to shaly blue limestone, with massive beds below. The exact contact is concealed, but the lava and limestone are within a few feet of each other. The lava at this point evidently flowed out on the limestone floor and engulfed loosened fragments of limestone that lay on the old erosion surface, forming a basaltic breccia of limestone fragments which are baked red and partly altered to epidote (see figure 9). The upper part of the flow is a dense lava, with small amygdules, which incloses few or no fragments of the underlying lime-

[26] S. G. Gordon: Idem, p. 357.

[27] A. I. Jonas: Pre-Cambrian and Triassic diabase. Bull. Am. Mus. of Nat. History, vol. xxxvii, 1917, p. 177.

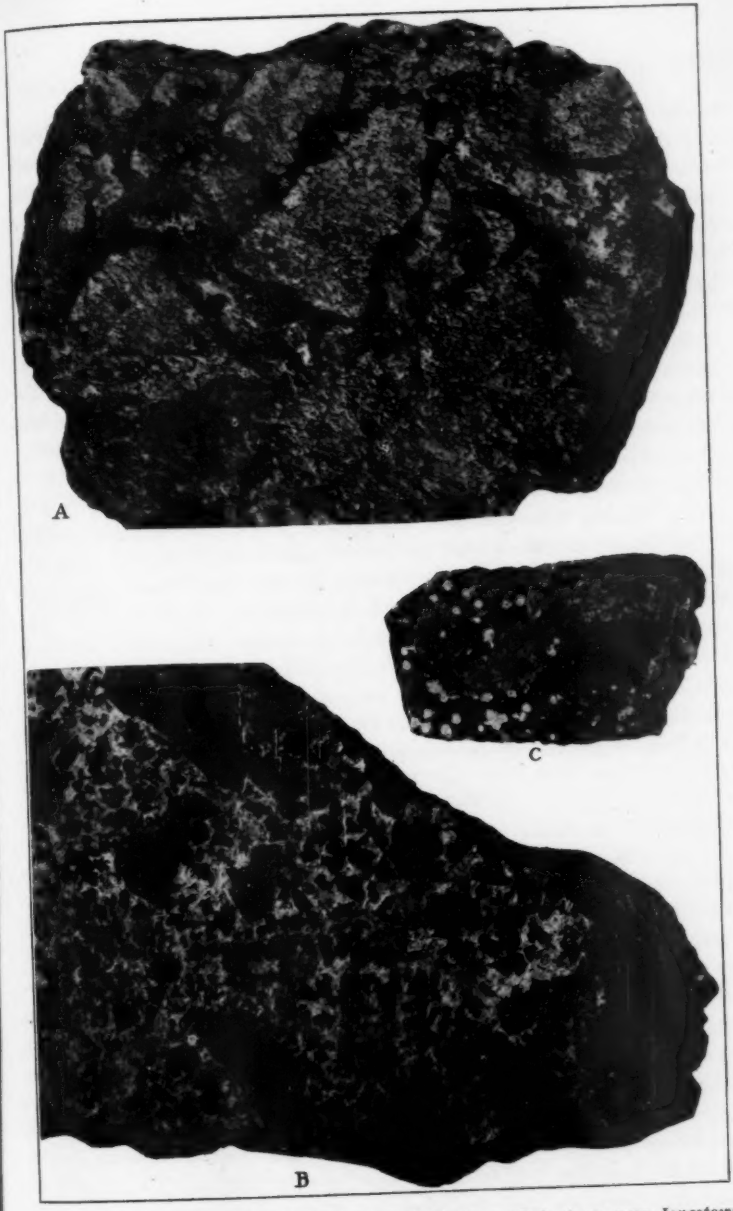

FIGURE 9.—*Basaltic volcanic Rocks from the Martinsburg Shale Area, near Jonestown*

A. Breccia of baked limestone fragments inclosed in a dense vesicular basalt from the base of the lava-flow at Bunker Hills.

B. Flow breccia of basalt fragments cemented by calcite, from near the top of the lava-flow, North Bunker Hills.

C. Dark-green vesicular basalt, the amygdules of which are filled with white and green calcite. The pitted weathered surface is the result of removal of the calcite by solution from the amygdules.

stone. The lava is overlain by unaltered red sandstone and shale, showing that the flow cooled before it was followed by deposition of shaly sediments. The lava-sheet of the northern ridge of the Bunker Hills, which has at its base a similar basal volcanic breccia composed of limestone fragments resting on massive blue limestone and dolomite, is undoubtedly the same flow as the southern sheet repeated by faulting. The basal contact, exposed in the south bluff of Swatara Creek at the railroad bridge of the Lebanon and Pine Grove branch of the Philadelphia and Reading Railroad, dips steeply southward and shows a few inches of soft purplish shale lying between the lava and the limestone floor. The underlying limestone at this outcrop is blue black and coarsely crystalline, some beds of which have been turned slightly green, a metamorphic effect which may have been produced by the heat of the lava-flow.

No hard white sandstone like that which forms the northern ridge of the Bunker Hills has been observed to overlie the southern outcrop of the basalt lava-sheet, and its absence would throw doubt on the conclusion that the two outcrops of lava are the same sheet repeated by faulting. However, the sandstone is believed to be present with the lava in the southern exposure, but to be less resistant or thinner, so that its outcrop was not observed. It is possible that the sandstone in the northern outcrop has been somewhat hardened by secondary deposition of silica from waters that circulated along the adjacent fault, which may also have obliterated its sedimentary bedding.

PROBABLE VOLCANIC ASH

Besides the basalt lava-flow at Jonestown, other rocks that are probably of volcanic origin occur in the shale, not only near Jonestown but at many other localities. The hard purple and green shales which have been observed near the base of the Martinsburg and Cocalico shales at many places are believed to be altered ash, related to the period of vulcanicity observed at Jonestown. The composition of the purple and green shale is such that if they are of volcanic origin they represent the product of an acidic (silicic) eruption and not a basic (subsilicic) one like that at Jonestown, but acidic ash eruptions are known to have accompanied or alternated with basaltic flows in volcanic regions. The purple and green shales are everywhere near the base of the Ordovician shale, and in the valley of Quittapahilla Creek, 3 miles north of Annville, they lie at the base (see section, page —) in contact with the limestone that underlies the Martinsburg, which is the exact

stratigraphic position of the basalt flow at Jonestown, only 6 miles to the northeast.

Although the study of thin-sections of the green and purple rock under the microscope has not yielded conclusive evidence of the volcanic origin of the material, its close resemblance in color and texture to volcanic slate, its occurrence in the same stratigraphic position as the lava at Jonestown, its association in most places with a hard white sandstone like that at Jonestown and with distinctive arkosic calcareous beds in other places, and its wide distribution at one horizon point strongly to its volcanic origin. It would be difficult to explain the deposition of so thin a layer of such a distinctive sediment over an area at least 100 miles along the strike and 40 miles across the strike on the basis of unusual climatic conditions or controlling factors other than volcanic eruption.

The presence of volcanic ash in the form of spotted green and purple shales, and especially of a lava-flow, in Ordovician rocks of southeastern Pennsylvania is of more than local interest, for these rocks may throw light on the source of similar volcanic shales in other parts of the Appalachians. Beds of volcanic ash in the form of bentonite interbedded with limestone and shale ranging in age from Chazy to Trenton have been reported from Virginia, Tennessee, Kentucky, Alabama, and central Pennsylvania.[28]

The basalt at Jonestown determines the proximity of a volcanic vent from which lava flowed, and it is probable that some of the acidic volcanic ash interbedded in the sedimentary rocks may have come from the same or a near-by vent. Unlike a lava-flow, volcanic ash, which is blown high in the air, may travel a long distance from its source before settling, and generally results in a thin but widespread deposit.

The determination of the precise position in the geologic column of the bentonite ash beds in central Pennsylvania and elsewhere has a bearing on the problem of their source and possible relation to the Jonestown vent.

E. O. Ulrich and Charles Butts[29] report the presence of bentonite in

[28] Thomas L. Watson and S. L. Powell: Bull. Geol. Soc. of Amer., vol. 21, 1910, p. 782.
Idem: Amer. Jour. Sci., vol. xxxi, 1911, pp. 33-44.
Wilbur Nelson: Bull. 25, Tenn. Geol. Survey, 1921, pp. 46-48.
Idem: Bull. Geol. Soc. of Amer., vol. 33, 1922, pp. 605-615.
Idem: Bull. Geol. Soc. of Amer., vol. 37, 1926, pp. 149-150.
C. A. Bonine: Report of Committee on Sedimentation; Research Council, Division of Geology and Geography, 1926, pp. 4, 5.
Charles Butts: Spec. Rept. 14, Geol. Survey Ala., 1926, pp. 113, 131.

[29] Personal communication.

limestone quarries at Bellefonte, Center County, Pennsylvania, in the following positions:

Lowville limestone (early Black River).

Carlim limestone (middle Chazy)
- **Bentonite, 1 foot.**
- **Lemont member (*Maclurea magna* zone)**
- **Bentonite, 1 foot.**
- **Lower member.**

They also report finding, in 1926, three thin bentonite beds at a higher horizon, close to the Black River-Trenton contact, at Salona, Clinton County, Pennsylvania. These latter beds are approximately at the horizon of the purple and green shales, of probable volcanic origin, near the base of the Martinsburg in southeastern Pennsylvania, and of the basaltic lava at Jonestown. Butts reports[30] at Ragland and near Attalla, Alabama, two thin beds of bentonite in the upper 15 feet of the Little Oak limestone, of upper Chazy age; another bed in limestones of Lowville (early Black River) age, and a third, at the base of limestone of Trenton age. The two latter beds are approximately at the horizon of supposed volcanic ash and of the lava near Jonestown.

Résumé of Relations of the Shale to underlying Limestones

Southwest of Susquehanna River the Martinsburg shale conformably overlies an apparently continuous sequence of limestones which contain Black River fossils at the top and Lower Cambrian fossils at the bottom. The Chambersburg limestone of Black River age is absent east of Susquehanna River, and the Martinsburg and Cocalico shales in most places lie unconformably on older limestones—Beekmantown, Conococheague, and Elbrook (see figure 10). Northeast of the Susquehanna the Leesport limestone, a dark argillaceous "cement rock" underlies the Martinsburg shale in places and contains fossils tentatively assigned to the lower Trenton. Near Delaware River and eastward in New Jersey the Jacksonburg limestone of Black River and Trenton age underlies the shale. While the Jacksonburg and Chambersburg limestones were probably synchronous deposits, the basins of deposition were separated by a land barrier, for the fauna of the Jacksonburg limestone is regarded by Ulrich as a northern Atlantic type, distinct from that of the Chambersburg limestone, which is regarded by him as a southern Atlantic fauna.

The irregular occurrence of the Leesport limestone beneath the shale may be the result of post-lower Trenton uplift and erosion, before the

[30] Op. cit.

deposition of the Martinsburg, or may be due to the local and restricted deposition of the Leesport limestone. The fact that it lies on Beekmantown limestone east of Womelsdorf and in Oley Valley shows that there was a post-Chazy period of erosion which removed the limestones of Stones River and Black River age before the Leesport limestone of probable lower Trenton age was deposited. It seems reasonable to con-

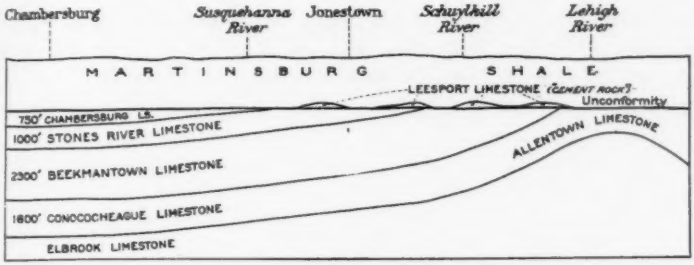

FIGURE 10.—*Sketch Section along southeast Edge of main Shale Belt*

Showing unconformity by overlap of Martinsburg shale, and probably of Leesport limestone ("cement rock") of Trenton age, onto older rocks down to the limestone locally called Allentown (lower Ozarkian of Ulrich). In the Schaefferstown and Shillington areas to the south the shale overlaps still lower, apparently onto the Elbrook limestone.

clude, therefore, that the irregular distribution of the Leesport limestone is due to the fact that it is a calcareous deposit representing the initial part of the shale deposition, and that the unconformity beneath the Martinsburg shale and that beneath the Leesport limestone are the same and represent a post-Chazy, pre-lower Trenton, uplift and erosion.

CONCLUSIONS

A marked unconformity exists at the base of the Martinsburg and Cocalico shales east of Susquehanna River, the lowest beds of shale of lower Trenton age overlapping rocks as old as Elbrook limestone of Middle Cambrian age.

The unconformity beneath the Leesport limestone ("cement rock") of probable lower Trenton age is probably the same as that beneath the Martinsburg shale, and the unconformity and overlap began in post-Chazy and pre-Trenton time.

Certain "cement rock" at Egypt, northwest of Allentown, is of the age of the upper Ozarkian of Ulrich and is not the same as the Leesport limestone, or "cement rock," of probable lower Trenton age.

A basaltic lava bed at Jonestown, Pennsylvania, is at the base of the Martinsburg shale and was erupted in early Trenton time.

Certain purple and green shales which occur near the base of the Martinsburg and Cocalico shales at or about the horizon of the basaltic lava are believed to be altered volcanic ash and to represent the same period of vulcanicity.

The volcanic ash in the form of bentonite found in rocks of Chazy to Trenton age in central Pennsylvania and other parts of the Appalachians, particularly that which is of late Black River or lower Trenton age, may have come from the same or a near-by vent as the one from which the Jonestown lava came.

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MEANING OF MEANDERS IN TIDAL STREAMS

BY MARIUS R. CAMPBELL

(*Presented in abstract before the Society December 28, 1926*)

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INTRODUCTION

When, in 1917, the contour maps of the Coastal Plain portion of Virginia appeared, the writer became interested in certain peculiarities of James River and adjacent streams, as represented on these maps, and a close study was begun to see if their meaning could not be determined from the maps. The features in question consisted in upland and floodplain meander scars,[2] indicating the former positions of meanders when the stream was flowing at higher levels than it does today, and meanders, generally more or less intrenched, in the present course of the tidal portion of the stream. The writer became interested in these features because it seemed probable that, if they could be correctly interpreted, they would throw considerable light on the conditions of the streams which formed them, particularly as to whether they were then,

[1] Manuscript received by the Secretary of the Society April 20, 1927.
Published by permission of the Director of the United States Geological Survey.

[2] The term meander scar heretofore has been applied only to those crescentic scars in the upland bordering a stream, which mark the positions of abandoned meanders. The writer proposes to broaden this concept so that the term may be applicable to any scar that marks the position of a former meander, whether it be on the upland or on the floodplain of the stream. This appears to be more logical than to restrict it, as has been done, to only one kind of scar when there are others of equal importance that should be recognized. This view of the case makes it desirable to divide meander scars into two classes: (1) upland meander scars or crescentic cuts in the upland bordering a stream, which were cut by lateral planation on the outer part of the meander loop; and (2) floodplain meander scars, a class of scars which includes any and all features on a floodplain that mark the former course of a stream meander.

as now, flowing at tidelevel, or were normal streams with an appreciable grade to their channels, and this knowledge would aid materially in determining the crustal movements that have taken place in the Embayed Section of the Atlantic Coastal Plain.

As James River, from Hampton Roads up to City Point, a few miles below Richmond, is at the present time a tidal stream or estuary, the first question that presented itself was: Could a stream, such as the James, develop meanders under present conditions where it is flowing at tidelevel, or, if meanders were already developed, is there any tendency on the part of a tidal stream to cut them off? In order to solve this question, it appeared to the writer necessary to begin a general study of the behavior of streams which, in their upper courses, flow under normal stream conditions, but, on approaching the sea, cross a belt of coastal plain in which they flow at sealevel. It also seemed desirable not to confine the study to streams carrying approximately the same volume of water as the James, but to study some of the largest rivers as well as some of the smallest which enter the sea under the conditions specified above.

Mississippi River

Mississippi River, the largest on the continent and one that carries an enormous volume of water and sediment, affords an excellent example of the behavior of a large river as it enters the flat coastal plain of its delta in southern Louisiana. As almost every one who reads this paper is more or less familiar with the course of the Mississippi, no map is given here, but from any map available it is apparent that the northern portion of the river has a very different pattern or plan from the southern portion, and that the place of change is a little below the city of Baton Rouge, Louisiana. Above this city the river flows in a very serpentine course, and its floodplain, for a distance of many miles on either side of the channel, is characterized by many oxbow lakes and bayous in various stages of obliteration, which mark former meanders that have been cut off and abandoned, and by many floodplain meander scars, such as shallow crescentic swales or even minor stream courses, that point to a time when the river in many places has wandered even more widely than it does today. If it were not for the levees and revetments built by the engineers, the river at every flood stage would change its course at some point or points, cutting off old meanders and developing new ones; this shows that, if unhampered, the natural tendency of the Mississippi is to shift its course. On the other hand, the channel below

Baton Rouge is marked by few meanders and most of its course to the Gulf is remarkably straight. Not only are there few meanders in this stretch of the stream, but there are few, if any, meander scars, indicating that in recent geologic time there have been few changes in the channel, though the river here, as well as above Baton Rouge, is subject to floods, the only difference being that in the lower stretch the flood water passes directly to the Gulf of Mexico, whereas, in the upper stretch, it returns to the main channel as soon as the flood begins to wane.

From this description it is apparent that the two sections of Mississippi River are totally different, not only in the patterns developed by the stream, but also in the general behavior of the river. Thus, north of Baton Rouge the river has great energy because of its volume and descent, and this energy is largely devoted to the corrasion of its banks, which if successful, results in a change of its channel; south of Baton Rouge, owing to the inflow from Red River, the volume of the stream is greater than it is above that city, but the stream exerts little erosive energy on its banks; it devotes its excess power to the deepening of its channel.

The difference in the two stretches of the river has been recognized by the army engineers, who make the following statement:[3]

"In the above description of caving banks and shifting bottom of the Mississippi River, little has been said of the river below the mouth of Red River, since in this section of the river the boat channel has always had several hundred feet of width over a depth far in excess of that at the river mouth, and no work of channel improvement has been necessary, except the removal of occasional snags and the protection of caving banks along city wharves and landings and at a few places where an undermining of the levee might cause exceptional danger to the river from crevasses. For a long term of years all ocean steamers able to go from the Gulf through the passes up the Mississippi River to New Orleans have been able to go fully 175 miles farther up the river with perfect ease and safety, to and past the cities and towns of Donaldsonville, Plaquemine, Baton Rouge, and Bayou Sara."

The engineers give the following figures for the elevation of the surface and the depth of water above and below Baton Rouge:

Height of low water above Gulf level:	Feet
Saint Louis, Missouri	377.9
Cairo, Illinois	270.0
Memphis, Tennessee	181.5
Vicksburg, Mississippi	39.7

[3] Report on a survey of Mississippi River from St. Louis to its mouth. 61st Congress, 1st session, House Documents, vol. 1, pp. 34 and 48, 1909.

	Feet
Mouth of Red River	3.0
Carrollton, Louisiana	—1.7
Fort Jackson, Louisiana	—1.4
Head of passes	0.0
Average depth of channel at low water:	
Saint Louis to Cairo	18.0
Cairo to Memphis	31.5
Memphis to Vicksburg	37.0
Vicksburg to Red River	48.5
Red River to New Orleans	84.0

Although the average depth of water below Red River is 84 feet, the profile of the lower river shows that in many places below Baton Rouge the Mississippi has a depth at low water of more than 200 feet.

One naturally questions why such a great change occurs at or near Baton Rouge. If the rocks over which the river flows changed greatly in character at this point, then such a change in the behavior of the river as that noted above could be easily explained, but as there is little or no difference in the material over which the water flows in this vicinity, it is necessary to appeal to some other cause or condition to account for the change.

From the table of elevations of low water in the river that has just been given it will be seen that above Baton Rouge the river is flowing in a comparatively shallow channel which is distinctly above the level of the sea, and therefore is working under normal stream conditions; but below Baton Rouge it is flowing in a deep channel under abnormal conditions, for it is flowing at or below the level of the water of the Gulf of Mexico. The change, therefore, from a position above sealevel to one at or below that level seems in some way to be the controlling factor in the change of regimen of the stream.

In normal streams the tendency to develop meanders is inversely proportional to the gradient of the stream—that is, where the gradient is high or steep, few, if any, meanders are developed, but where the gradient is slight and the land flat, the meanders are at their maximum. This rule, however, does not apply to the Mississippi, for where the gradient is flattest (below Baton Rouge) there are almost no meanders to be found. Here, again, sealevel seems to be the line at which normal stream action ceases, and the stream behaves differently below that level from what it does above it.

As the main object of this paper is to demonstrate the proposition that the action of running water at sealevel is very different from what

it is above that level, it is not necessary to inquire what is the cause of this difference, but the geomorphologist at once wants to know why this difference exists. The writer is not prepared to answer this question, because it doubtless involves a careful analysis of the mechanics of stream-flow under diverse conditions, and consequently is highly complicated and involved. Some may argue that the straight course of the Mississippi in its lower reaches is due to the fact that much of its seaward growth has been accomplished by the building forward of its delta, and that under such conditions there would be little or no tendency to follow a crooked course. It is quite possible that the lower river extended its course in this manner, but even if that be true it does not explain the present apparent inactivity of the river in corrading its banks and in developing meanders. The seaward extension of the Mississippi from Baton Rouge must date far back into Tertiary time, and, if that is the case, ample opportunity has been afforded the river to change its course, but it does not seem to have accomplished such a change. Others may hold to the opinion that the present stream below Baton Rouge is so closely confined by levees that the river has little opportunity to show any tendency that it might have to corrade its banks. This can hardly be the case, at least to any marked extent, because the levees have been built in comparatively recent time, and before the advent of the white man the river was unhampered in its activities, but despite this unhampered condition no meanders of consequence were developed, or traces of them would be apparent at the present time in the form of floodplain meander scars.

It is possible, as believed by some, that the earthy matter carried by the river is so fine in the lower reaches that it does not provide a tool by which the water may corrade its banks, but it does not seem probable in view of the fact that in this part of its course the river corrades the bottom of its bed, reaching in places depths of more than 200 feet below sealevel. It is also possible that the river is too deeply intrenched in its lower course (averaging 84 feet below the mouth of Red River) to seek other courses to the open water of the Gulf or to cut off a bend in the channel of the river itself. Theoretically this seems possible, but the persistence of the channel seems to indicate that the river has no inclinaton to corrade its banks, and if this is true it would have no means of cutting off meanders or of developing new ones. Despite the great system of levees which now hems in the water of the lower Mississippi, crevasses are sometimes formed in stages of high water and the river seeks temporary relief in the diversion of part of its volume directly

to the Gulf, and certainly in prehistoric time such diversions must have been of frequent occurrence; but despite such temporary lapses the river has maintained its course, and this in itself is positive evidence that in all such cases there has been little or no tendency for the river to corrade its banks and by this means develop meanders. The forming of crevasses must therefore be regarded as merely affording temporary relief to the stream and in no sense tending to cause the stream to assume a new course or to develop meanders. No theory of change in this part of the river's course appears to be supported by tangible evidence on the ground, by features showing on the maps of the region, or by reports of observers; hence it is reasonable to conclude that here the river is fairly stable and in recent times, at least, has made no decided change in its course.

The writer is not prepared to go into a thorough analysis of all of the causes and conditions that produce stability in the lower course of this great river, but he is inclined to believe that when the river reaches tidelevel the current is flowing in a more or less well defined channel of water and that the confining banks on either side are banks of water rather than banks of earthy material. In other words, the earthen banks are blanketed and protected by a mass or curtain of stagnant water which effectively prevents them from being corraded by the current, no matter how much earthy material is carried by the stream nor how closely it is confined. It is quite conceivable that the effectiveness of such a mass of stagnant water, or even its existence, might depend largely upon the volume of water carried by the stream. Thus in times of flood it is hardly conceivable that the current would be entirely blanketed, but its corrasive power is doubtless greatly reduced.

The power of the current to corrade the earthen banks at stages of high water is recognized by the engineers, as shown by the quotation on page 539, but the amount of corrasion accomplished is infinitesimal as compared with that which the river accomplishes under similar conditions in its upper reaches.

Judging from all of the facts now available, there seems to be little ground for doubting the inert condition of a river of the first order of magnitude after it reaches tidelevel or stagnant water of any kind. This inert condition means that the stream has no inclination to form meanders and none to cut off meanders already formed.

San Jacinto River

I shall now ask you to consider the behavior of a small stream which, through recent subsidence of the coast, now reaches tide water several

miles farther inland than it did before the subsidence occurred. The stream in question is San Jacinto River, a small stream, which flows into the head of Galveston Bay, about 30 miles north of the city of Galveston,

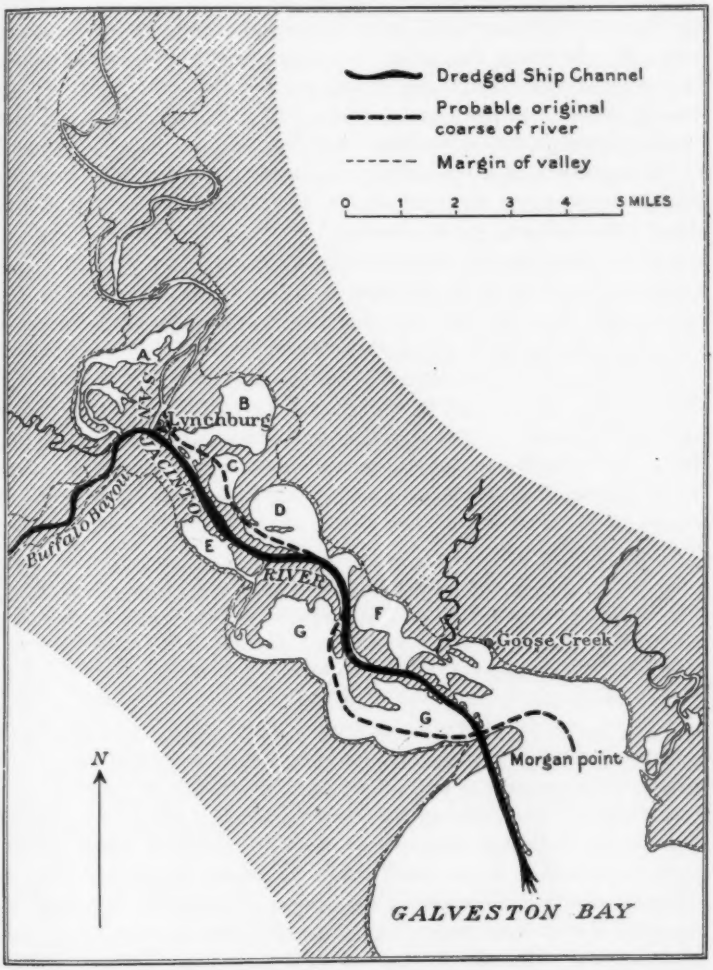

FIGURE 1.—*Sketch Map of San Jacinto River, Texas*

Showing its meander belt in both normal and submerged conditions. A, Old River; B, Burnett Bay; C, Crystal Bay; D, Scott Bay; E, Peggy Lake; F, Black Duck Bay; and G, San Jacinto Bay.

Texas, and now is best known by the deep ship channel which has been dredged up this stream and its affluent, Buffalo Bayou, to the city of Houston.

Fortunately for the present inquiry, the geomorphic history of this stream is fairly obvious, and hence it is comparatively easy to determine what effect drowning has had on the normal activities of a small stream. San Jacinto River originally flowed southward to the Gulf over the smooth surface of the Coastal Plain. At the time this course was established the surface of the plain must have been very nearly horizontal, or, if established on a seaward-sloping plain, this plain must have been raised slightly along the coast so that the lower part of the stream became quite sluggish, for it developed very marked meanders (see figure 1) in a meander belt ranging in width from 2½ to 3 miles. Later, owing to the elevation of the land, San Jacinto River intrenched itself in this plain to a depth of 40 or more feet. Many changes doubtless occurred in the meanders as the entire meander belt was being cut down to the level of the lowest cut. The belt, however, was not uniformly cut laterally, for there are left to mark its sides many upland meander scars, as shown in figure 1. The meanders were developed almost to Galveston Bay. Evidently the stream of that time was flowing as a normal stream above tidelevel, for the meander scars in the lower part of the course are of the same character and magnitude as the occupied meanders above the area of submergence.

After the stream had nearly cleared its meander belt, there came a slight subsidence of the land, which permitted the water of the Gulf to enter the lower part of the river channel, flooding it for a distance of 10 miles, but the water rose only to within 30 feet of the original surface of the Coastal Plain. This leaves the old meander scars, which, as shown in figure 1, are the most striking feature of the region, as outlining the extent and form of the estuary. Unfortunately for our study, the recent history of this estuary is difficult to interpret because of the dredging of a ship channel from Morgan Point up San Jacinto River to Lynchburg, and thence up Buffalo Bayou to Houston. The writer has endeavored to find charts showing the condition of the estuary before any effort was made to improve the channel, but he was informed by the Coast and Geodetic Survey that the old charts do not show any soundings above Morgan Point. Because of this lack of data one can not be sure of the location of the natural channel from Morgan Point to Lynchburg, but the writer has assumed that it followed approximately the course indicated by the heavy broken line in figure 1. This is not strictly a median

course, but it seems quite certain that in no case did the channel impinge upon the meander scars. The evidence in favor of this course is the distribution of the sediment, which evidently must have been deposited largely, if not wholly, before the deep ship channel was excavated. The only place where positive evidence can be obtained regarding the position of the channel previous to the dredging of a ship channel is the stretch of river just above the mouth of Buffalo Bayou. Here the flooding due to the last subsidenec of the land has been sufficient only to fill an old channel known as the Old River (A). This seems undoubtedly to have been the channel followed by San Jacinto River just before the subsidence occurred, but after the subsidence this channel was abandoned by the river, which swung to the east into its present position near the middle of the meander belt. This change was probably caused by the flooding by tide water. It seems probable that the original channel below the mouth of Buffalo Bayou turned at Lynchburg and flowed through the west end of Burnett Bay (B), thence through Crystal Bay (C), and through the narrow channel into the south end of Scott Bay (D). From this place the channel seems to have corresponded with the dredged channel for about a mile and then swung to the west into San Jacinto Bay (G), as indicated in figure 1.

The conclusion from this example seems to be obvious that as long as the stream flowed above tidelevel it developed meanders in great abundance, but as soon as the land subsided below waterlevel the stream lost its tendency to enlarge its meander curves and tended rather to follow a median course in the meander belt from the upper end of the flooded area down to Galveston Bay. The reason for the change in the behavior of the stream seems to be the same as that given for the Mississippi—namely, that as soon as a stream reaches tide water the current flows in a bed of water which protects the earthen banks and thus prevents the current from corrading them, with the result that the current no longer follows the curves of the meanders, but is more likely to take short cuts across the submerged meanders.

James River

We have now considered two streams of very different volumes and environments, and it is obvious in both of these streams that there is no tendency either to develop meanders when the stream reaches approximately the level of the sea or to cut off any meanders that may have survived from a previous interrupted cycle of erosion. It now remains to examine the estuary of James River in Virginia from just below the

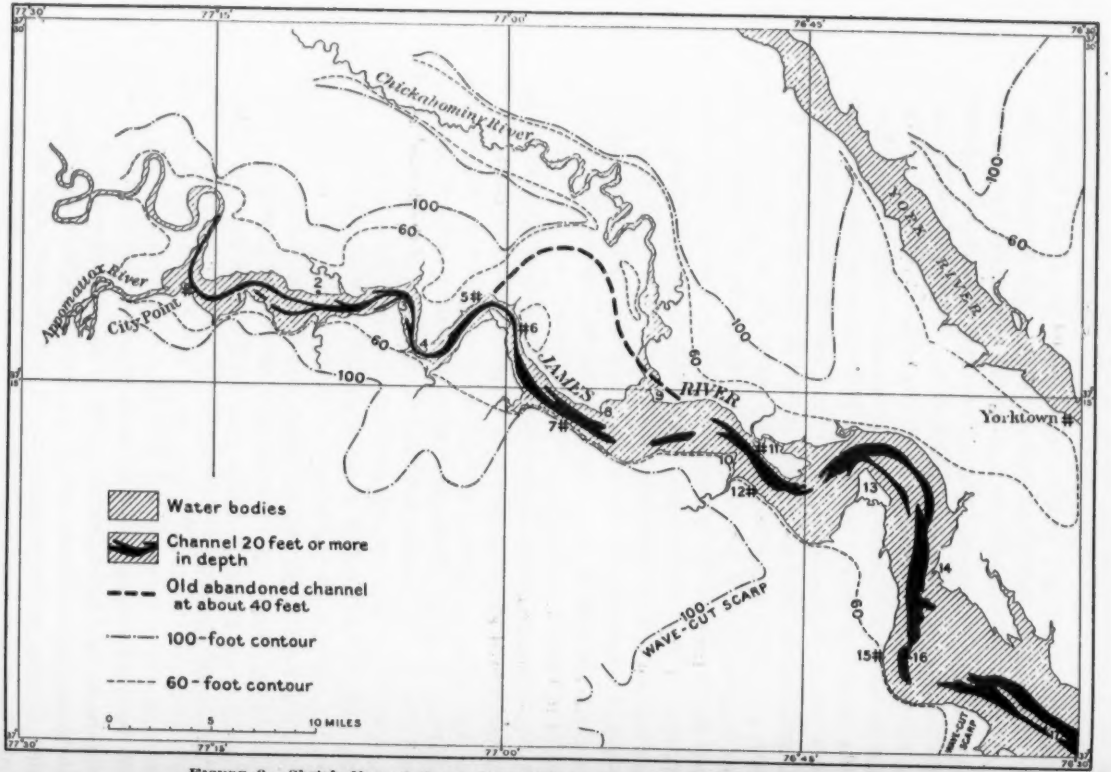

FIGURE 2.—*Sketch Map of James River Estuary from City Point to White Shoal Light*

Showing the deep channel and upland meander scars. (1) Jordan Point, (2) Westover, (3) Windmill Point, (4) Weyanoke Point, (5) Milton, (6) Oldfield, (7) Claremont Wharf, (8) Dancing Point, (9) Barrets Point, (10) Swann Point, (11) Jamestown, (12) Mumford, (13) [illegible], (14) Mulberry Point, (15) Ferguson Wharf, [illegible]

city of Richmond almost to Hampton Roads. At first sight one is struck with the similarity of this stretch of the river to that of San Jacinto River, Texas, which we have just considered. One gets the impression that James River once had a meandering course on a coastal plain which has been depressed, drowning the meandering valley of the river up as far as Richmond, but in this case the drowning has not been sufficient to submerge completely all of the meanders above City Point, at the mouth of Appomattox River, and allow the stream in the entire depressed area to take a median course in the meander belt, as is the case with San Jacinto River. As James River has not had an opportunity in all of its course to follow a median line in the meander belt, because of the lack of complete submergence, it will be necessary to examine critically the present channel of the stream to see whether or not it follows the same law that apparently controls Mississippi River and takes a median course in the submerged channel.

James River is a tidal stream from Richmond to Hampton Roads, but from the head of tide down nearly to City Point, at the mouth of Appomattox River, the stream behaves more or less as a normal river behaves and the drowning is not sufficient to submerge the floodplain and carry the water far inland beyond the immediate banks. From City Point to Dancing Point (8 on figure 2), a few miles above the mouth of Chickahominy River, the estuary is generally narrow, the water ranging in width from one-third of a mile to nearly 2 miles. The ship channel, which in most places is the natural channel, generally follows a median course, especially in the wider portions of the estuary. In the narrow portions, where the water is little or no wider than the normal stream above City Point, the current crowds the banks on either side, but even here there is no evidence that the current is appreciably corrading the banks, for the outline of the meander is not a perfect curve, as would be the case in homogeneous rocks where the current is actively cutting the outside of the bend.

With this general introduction in mind, it is desirable to examine the river as it is represented on the map, figure 2, to see if there are any places, however small, in which corrasion of the banks is going on.

At City Point, on the upper end of the drowned portion of the river, the water extends laterally far beyond the deep channel and at only one point does this channel come close to the shore. This is at the main wharf in the town, but, though deep water comes to the end of the wharf, there is no indication that the channel is encroaching on the land. From City Point to Jordan Point (1 on figure 2) the deep chan-

nel must at some time in the past have swung far to the south, for the bank on this side extends in an almost unbroken curve from one of these places to the other, but since the drowning occurred the deep channel (as shown by the black line) is located nearly in the middle of this broad course.

From Jordan Point (1) to Windmill Point (3) the river must originally have swung in a sharp curve to the south, as indicated by the meander scar, and then pursued a straight course nearly to Windmill Point (3). At the present time the meander just below Jordan Point (1) has been abandoned and the main channel is near the north bank, but there is apparently a remnant of another channel occupying a course midway between the meander scar and the present channel. This seems to mark a previous course that is now practically abandoned for the straighter course near the north shore. Opposite Westover (2) the channel is in the middle of the water body, and this position is held down to the beginning of the bend around Windmill Point (3), but with many short branches, which seem to indicate that the channel has shifted recently for short distances.

The bend or meander at Windmill Point (3) is an excellent example of the inability of the stream to crowd the outer bank. The water here has a considerable width, and as a consequence the main channel is not confined by any material barrier, but despite this freedom of movement there appears to be no tendency to scour the outer bank, for, as shown in figure 2, the black line indicating the deep channel crowds close to Windmill Point rather than to the outside of the curve.

The narrowest part of the estuary below City Point is the bend at Weyanoke Point (4). Here the water body is no wider than the normal stream in the vicinity of Richmond and, as a result, the deep channel is close to the outer bank and also to the inner bank, but, as far as one may judge from the chart, it does not impinge against the outer bank, although it flows very close to it. The argument in favor of little or no corrasion is that, although the meander is close against the 60-foot contour here, it has made no progress into the upland, for there is no indication of the development of a meander scar at this point. It is true that Weyanoke Point has grown somewhat in recent years, as is indicated by its low and marshy character; from this it would seem that there had been some extension of the point, but this has been so slight as to be negligible. The meander at this point developed by the present stream does not compare with the great meander that is indicated by the bend of the 100-foot contour to the south. The evidence here may not be regarded as

conclusively proving no development of a meander, but certainly, if there has been any such development, it has been so slight as to be of no importance.

At Milton (5) and Oldfield (6), on the next bend of the river, there is no indication of corrasion taking place on the outside of the curve. This is shown by the lack of regularity of the curve on that side and also by the position of the deep channel in the middle of the water body. It is interesting to note that in these narrow reaches of the estuary the deep channel is continuous and apparently is maintained without the aid of artificial means. This shows that the energies of the current are devoted to the scouring of the bottom of the river bed rather than to the corrasion of its banks. The action is similar to that which prevails in the lower Mississippi, though the results are not so conspicuous.

Below Oldfield (6) the deep channel is continuous to just below Dancing Point (8), but in this stretch, although the channel is near the south bank, there are no indications that it is corrading that bank. Opposite the mouth of Chickahominy River the estuary is wide and the current is not confined sufficiently to make it scour the bottom, and consequently the channel is neither deep nor definite, and dredging has to be resorted to in order that vessels may pass up the river to City Point.

Between Swann Point (10) and Jamestown (11) the current is somewhat more confined and the deep channel is maintained without much difficulty. This channel is close to the north bank, but there is nothing to indicate that it is crowding that bank or tending to swing in that direction.

A large meander scar in the south bank of the river between Scotland (12) and Hog Island (13) shows that at one time the current must have impinged against that bank throughout the whole extent of the curve between the points given above, but for some reason this course has been abandoned and now the deep channel is near the bank on the north or on the inside of the curve. This position would never have been assumed by a stream flowing under normal upland conditions; therefore it seems obvious that the meander was developed when the stream was flowing above sealevel and that it was deserted for the present course when the land sank and the drowning of the valley occurred.

The great northward bend or meander around Hog Island (13) is one of the most interesting features of the estuary of the James—first, because it is the most pronounced meander, and, secondly, because the deep channel, which is continuous around the bend, pursues a course

which by no possibility can be considered as impinging against either of its banks. Here we have the ideal median course—a course that never would have been assumed by a river flowing under normal conditions, or, if assumed, would not be maintained for any length of time. Not only is there a complete lack of observable tendency to enlarge this meander, but there is also a lack of tendency to cut off the one already developed. Hog Island (13) is low, being less than 10 feet above sea-level at its highest point, and the neck back of the point consists of a marsh in which there is a tidal channel extending from the river above the bend to the river below the bend. In a normal stream such conditions would greatly favor the cutting off of Hog Island in time of flood and the eventual establishment of the main channel south of the island, but the present condition has doubtless been maintained for a great many years and still there is apparently no indication that such a change is imminent. Altogether, the conditions at this curve are such as to prove conclusively that a stream flowing at tidelevel has no tendency to form meanders or to cut off meanders that may have been formed at some previous period when the conditions were different from those which prevail today.

Below Hog Island the estuary increases in size, ranging from 2 to 5 miles in width. The deep channel is, however, fairly constant and at considerable distance from the shore, so that wharves have to be built out some distance in order to load and unload freight and passengers on the river boats. Just below Point of Shoals Light (16) the deep channel is interrupted for a short distance, indicating that the movement of the current is not so constant here as it is in other parts of the estuary where it is more closely confined. It seems altogether probable that the inward-flowing tidal current tends to follow a straight course northwestward from White Shoals Light (17) and thus to scour out a rather shallow channel distinctly north of the channel maintained by the outward-flowing current. This view of the case is strengthened by a study of the chart of this part of the estuary, for this shows shallow channels across this point and also an interruption in the regular channel south of Point of Shoals Light, which is doubtless due to the interference of the tidal current with the normal stream current and the precipitation of sediment in the eddy caused by this interference. For the purposes of this paper it is not necessary to follow the estuary farther toward its mouth, as in this part the currents are more complicated, being a combination of stream current, tidal current, and currents set up in various directions by the force of the wind.

In summing up the evidence available on the maps of this part of the James River estuary, nothing has been found that in any way conflicts with the conclusions given in this paper, but, on the contrary, all of the facts as to location of channel and scour of the river banks appear to substantiate what the writer maintains—namely, that there is here no evidence that the current tends in any way to impinge on the banks and thus to develop meanders, and, if it shows no tendency to develop meanders, it certainly shows no tendency, however small, to cut off meanders which may have been inherited from a previous interrupted cycle of erosion.

Some who are familiar with this estuary have maintained that this tendency does exist here, because the banks are continually receding by the undermining of the water. This action is particularly prominent in the lower reaches, where the width of the water body is considerable. The writer is positive that the map shows clearly that the river current can not possibly accomplish this work, because it is at such a distance from the shore that its effect would be practically zero. By this the writer does not mean to question the statement that the banks are receding, but this recession can be accounted for by the attack of the waves, which in these wide stretches and under the stress of a violent wind must be of considerable force—certainly sufficient to accomplish this work.

Chickahominy River, shown on figure 2, also has features similar to those which prevail in the estuary of the James, except that they are on such a small scale that it is impossible to show them on the map here presented. This stream has a deep channel, similar to the deep channel of James River, except that in the case of the Chickahominy the deep channel is not continuous for a long distance, but is present in the point of each meander up to the place where the meanders terminate. As the water body is very narrow, it is difficult to determine the relation of the deep channel to the water body in general, but, so far as the writer can observe, it shows no tendency to impinge on the earthen banks, and, if so, can have no tendency to enlarge the meanders, but the Chickahominy can not be regarded as furnishing positive evidence on this question.

Conclusions and Application

If, therefore, it be granted that there has been presented sufficient evidence to substantiate the claim that streams flowing at tidelevel have no power to enlarge their meanders nor to cut off meanders that have

already been formed, then it is desirable to point out briefly some of the applications of the proposition to the practical solution of the geomorphic history of such a region as the Embayed Section of the Atlantic Coastal Plain. There are at least six well marked meanders in the deep-water channel of the James below City Point. At present the current in these meanders is flowing at sealevel, but the development of the meanders must date back to a time when the current in each was flowing above sealevel and of course under very different conditions from those which prevail today. The geologic date of origin of some of these meanders can be fixed quite definitely, but the date of formation of others may be very different, and the date of formation of some can not, with the data at present available, be fixed. It can, however, be definitely stated that all of them were formed above the level of the sea.

Bsides the meanders in the present channel, we know that there are other meanders indicated by great upland meander scars that are clearly outlined on the contour maps of this region. It was impossible to reproduce these on the small scale map here presented, so the generalized form of certain critical contours is given on figure 2. The region back of City Point and thence in general parallel with the estuary as far as Scotland (12) lies above the 100-foot contour and its surface is now generally regarded as of subaerial origin. When James River was flowing at the surface of this plain, it developed four meanders on the north side of the stream above Chickahominy River and two on the south side, as indicated by the great curves in the 100-foot contour line. At this time the shoreline crossed this area in a northeasterly direction in the vicinity of Scotland (12), as indicated on figure 2. All of these meanders persisted until the river had cut down to the 60-foot level, but the two on the south, as well as the uppermost two on the north, were abandoned at or near the 60-foot level, as indicated by the absence of a corresponding swing in the 60-foot contour. The meander north of Windmill Point (5) persisted, but with decreased radius, until the river cut below the 60-foot level and presumably until it reached the 40-foot level. The great meander on the point above the mouth of Chickahominy River persisted without a break until the river cut down to 40 feet. This is the latest one to be abandoned, for its old channel indicated on figure 2 by the heavy broken line is still visible with the high point of the meander spur showing at Oldfield (6) as an island in a sea of alluvium.

The last-mentioned case raises the interesting question as to whether or not a meander may be cut off by a stream flowing at tide level. It

has been repeatedly stated in previous pages that under such conditions as those specified above the stream shows no tendency to enlarge its meanders, and consequently no tendency to cut off the neck of a meander and cause its abandonment. This the author regards as unquestionably true, and yet there seems to be a possible method by which a meander at sealevel may be cut off. If, for instance, the current was still flowing

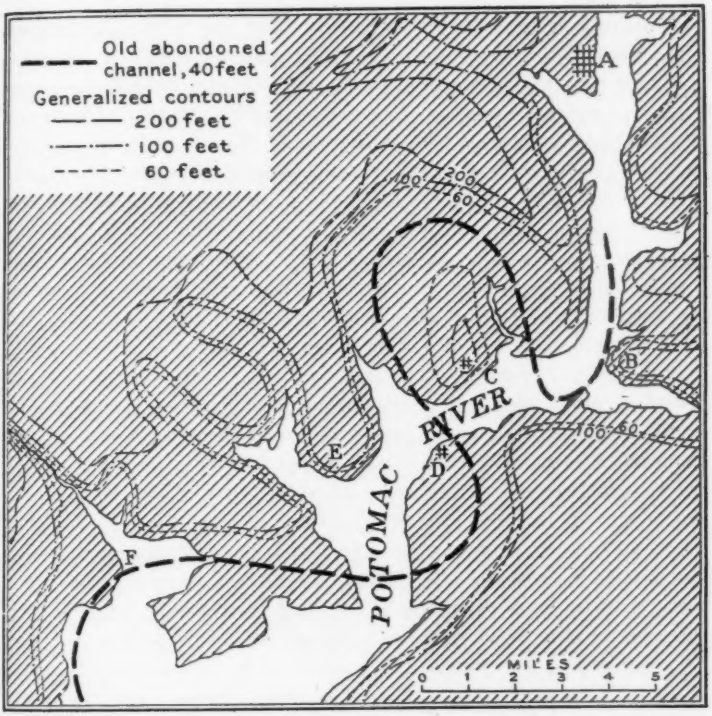

FIGURE 3.—*Sketch Map of Potomac River at Mount Vernon*

Showing cut-off meander and upland meander scars. (A) Alexandria, (B) Fort Washington, (C) Mount Vernon, (D) Marshall Hall, (E) Camp Humphreys, and (F) mouth of Occoquan Creek.

around the meander shown by the broken line north of Oldfield (6), and if the neck of the meander southwest of Oldfield (6) was slightly lower than the outer point within the meander, then on a slight regional subsidence the current might be diverted from the roundabout course shown by the broken line to the present course by Oldfield (6) and

Claremont Wharf (7) and the meander abandoned. A slight elevation subsequent to the abandonment might leave the old channel north of Oldfield (6) in the condition we see it today; in other words, just as it was abandoned and with all the marks of a used channel still clinging to it. Such an occurrence is certainly possible, but it involves so many slight changes of level that it seems hardly probable that it ever occurred.

The three meanders between Jamestown (11) and White Shoals Light (17) present little evidence by which their date of origin can be established, but they must have been developed since the 90-foot beach near Scotland (12) was abandoned by the uplift of the region. They were, therefore, in all probability developed on the 60-foot plain when it was first raised above sealevel or on some subsequent plain at a lower level. As the outline of the 60-foot terrace shows meander scars corresponding to the present meanders of the river, it seems highly probable that these meanders were originally dveloped on that terrace, but this similarity of outline should be taken as suggestive only, and should be regarded only as proof in case it can be supported by other facts.

The probable value of this line of evidence in the interpretation of the geomorphic history of this region is still further illustrated by an occurrence of an abandoned meander on Potomac River at a locality that has been visited by a great many thousand visitors—Mount Vernon, the home of General Washington. Mount Vernon is situated on the west bank of Potomac River, some 20 miles below Washington, on the point of an old meander spur which projected from the Maryland side and around which the river once curved in a very symmetrical meander. The situation at Mount Vernon is represented by the sketch map, figure 3, which shows Potomac River from Alexandria, Virginia (A), southward by Fort Washington (B), Mount Vernon (C), Marshall Hall (D), Camp Humphreys (E), to a point some distance south of the mouth of Occoquan Creek (F). The heavy broken line shows the former course of Potomac River where a little below Fort Washington it swung north across its present course and made a great curving meander, inclosing Mount Vernon. From this bend it swung back across its present channel in the vicinity of Marshall Hall, and thence turned west to the mouth of Occoquan Creek and from that point south to the present channel. The evidence of such a course is unmistakable, but its principal value in the present paper is the light it throws on the attitude of the land as regards sealevel. At present the Potomac River from Washington to its mouth is flowing at sealevel, but the old meander back of Mount Vernon, as shown by figure 3, was cut in an upland

which now is at least 200 feet above sealevel. There is evidence in the vicinity of Washington, which it is not appropriate to introduce here, which shows that originally the Potomac did not turn south at Washington, but continued eastward across the District of Columbia and discharged its water and accompanying sediment onto a big alluvial fan that sloped down to the present mouth of the river. At that time the river was flowing on a terrace that is now 250 feet above the sea. The river blocked its course by the fan that it built and then took the southward course past Alexandria with which we are familiar. It has been argued that at that time its course below Washington was an estuary and that the estuary has persisted to the present time, but, if the writer has proved his case, that could not have been true, for the river developed the Mount Vernon meander on this new course, and it could not have done so if the river were flowing at sealevel.

Again, the meander at Mount Vernon was cut off when the river was flowing 40 feet higher than it is today. The remains of the old channel are so perfect that there can be no question about its being an old channel of Potomac River. As shown previously, the cutting off of meanders can not be regarded as positive evidence of the action of running water, but the chances of it having occurred under any other condition are so remote that they are hardly worthy of consideration.

Serpentine runways in tidal marshes have been cited as evidence that meanders are formed at sealevel, but, while the writer has little first-hand knowledge regarding the action of streams under such conditions, he is strongly of the opinion that the formation of tidal runways has little or no bearing on this subject, for the reason that such runways are cut by the rushing water of the incoming and the outgoing tides, and at such times any lateral cutting that might be done would be above actual sealevel and would be done under the laws that control corrasion by running water.

In conclusion, the writer believes that a sufficient body of facts has been presented to show conclusively that meanders do not develop at tidelevel, and if that is correct, then their presence or absence may be taken as indicating the attitude of the surface of the land at the time of their formation. The cases cited are all of tidal streams, but the problem is not necessarily concerned with tidal phenomena; it is applicable to all submerged stream valleys, no matter whether their submergence is due to the invasion of the sea or to that of fresh water from some inland lake.

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TERTIARY PHYSIOGRAPHIC DEVELOPMENT OF PORTO RICO AND THE VIRGIN ISLANDS

BY H. A. MEYERHOFF [1]

(*Read before the Society December 28, 1926*)

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REVIEW OF EARLIER PHYSIOGRAPHIC STUDIES

The Tertiary physiographic history of Porto Rico was outlined by A. K. Lobeck in 1922.[2] His work emphasizes the importance of early and middle Tertiary events, but does not differentiate any landforms of late Tertiary or Quaternary age, except for the relatively recent dissection, marginal drowning, and coastal modification. In 1924 and 1925 the writer studied the physiography of the Virgin Islands, Culebra, and Vieques, which lie immediately east of Porto Rico (figure 1). The landforms of these islands run those of Porto Rico a close parallel, and in the reports on their physiography [3] the writer has followed, with only minor

[1] Manuscript received by the Secretary of the Society May 25, 1927. Introduced by Charles P. Berkey.

[2] A. K. Lobeck: The physiography of Porto Rico. Scientific Survey of Porto Rico and the Virgin Islands. New York Academy of Sciences, vol. i, pt. 4, 1922.

[3] H. A. Meyerhoff: The physiography of the Virgin Islands, Culebra, and Vieques. Scientific Survey of Porto Rico and the Virgin Islands. New York Academy of Sciences, vol. iv, pt. 1, 1926; pt. 2, 1927.

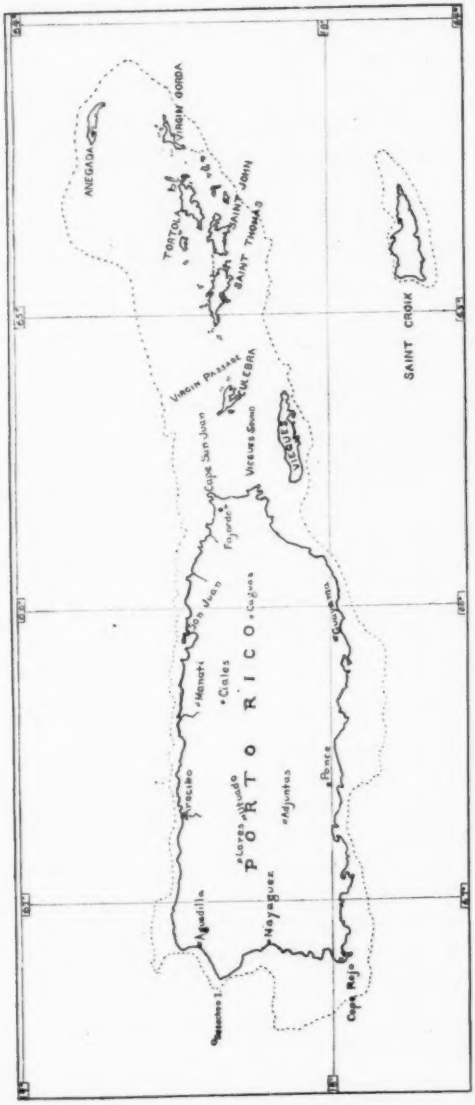

FIGURE 1.—*Outline Map of Porto Rico and the Virgin Islands*

refinements and revisions, the general chronologic outline established by Lobeck. The development of Porto Rico and the Virgin Islands, as determined in Lobeck's report and in the author's studies, is summarized and compared, and the physiographic events are approximately dated in the accompanying table.

Examination of the first two columns of the table should lead to a suspicion that the history as outlined is unbalanced. The occurrence of two or three cycles of extensive denudation in Eocene and Lower Oligocene time as against a single incompleted cycle since Middle Miocene time is difficult to explain, even by the exposure of deeper and more indurated, hence more resistant, rocks, in the course of long and profound erosion. On purely hypothetical grounds, therefore, the possible existence of younger erosional levels should have been given more thorough consideration, and the proofs of the early Tertiary age of the three peneplanes already identified should have been scrutinized more closely both by Lobeck and by the writer in his earlier studies. It is to be admitted, however, that these are afterthoughts which have followed on the discovery that one of the peneplanes, formerly considered early Tertiary, must be redated as late Tertiary. The purpose of this paper is, therefore, to review the earlier conclusions reached by Lobeck and by the writer and to consider the evidences of late Tertiary cycles of erosion. The significance of such erosional forms as were developed in the latter part of the Tertiary and in the Quaternary in dating the block-faulting which has separated the island of Saint Croix from the northern Virgin Islands and Porto Rico will also be pointed out.

Geographic Setting

Porto Rico is located at the eastern extremity of the Greater Antilles. The island is 105 miles long and 35 miles wide, but finds an eastward extension, 85 miles long, in the submarine platform from which rise the northern Virgin Islands, Vieques, and Culebra (figure 1). These small islands are erosional remnants of what was formerly an upland continuous with that of Porto Rico. Differential warping has partly drowned the Virgin Islands area, while Porto Rico was elevated by the same movement. One other island, now detached, belongs to this group—the island of Saint Croix. It is 18 miles long and rises above a platform 30 miles in length. Although the island is now separated from the other Virgin Islands and from Porto Rico by 32 miles of open water, which attains minimum depths of 6,000 feet and a maximum of 15,000 feet, its geology is so like that of the northern islands that a former connec-

Tabular Outline of the physiographic History of Porto Rico and the Virgin Islands

	Lobeck, 1922 Porto Rico	Meyerhoff, 1926 Virgin Islands, Culebra, Vieques	Meyerhoff, 1927 (present report) Porto Rico, Culebra, Vieques, Virgin Islands
Recent	Slight emergence Moderate marginal submergence	Slight emergence Maximum submergence	Slight emergence Maximum submergence
Pleistocene	Dissection; marginal submergence in east	Block-faulting (?) Migratory strandline during glacial stages Widespread but partial submergence	Block-faulting Partial submergence east of Porto Rico, with migratory strandline during glacial stages Uplift, with warping, followed by youthful to mature dissection of Caguana peneplane
Pliocene	Uplift, followed by young to mature dissection of coastal plain and oldland	Uplift and warping, followed by mature to old dissection of coastal plain and oldland	Uplift, followed by extensive peneplanation of coastal plain and oldland (Caguana peneplane)
Miocene: Upper			Uplift, followed by extensive peneplanation (upper, or Saint John, peneplane)
Miocene: Middle, Lower	Coastal plain accumulation	Coastal plain accumulation	Coastal plain accumulation
Oligocene: Upper, Middle			
Oligocene: Lower	Uplift, followed by second cycle of peneplanation, marginal to first (lower peneplane) First cycle of peneplanation, leaving only a few monadnock residuals (upper peneplane)	Uplift, followed by third cycle of partial peneplanation (lower peneplane) Uplift, followed by second cycle of partial peneplanation (intermediate, or Saint Croix, peneplane) First cycle of peneplanation (upper, or St. John, peneplane)	Partial peneplanation (lower peneplane, or subcoastal-plain erosional surface) Record not preserved, but probabilities of earlier cycles of erosion are strong
Eocene			
Paleocene			
Upper Cretaceous	Intrusion, folding, uplift, making complex mountainous oldland Accumulation of volcanics and sediments	Intrusion, folding, uplift, making complex mountainous oldland Accumulation of volcanics and sediments	Intrusion, folding, uplift, making complex mountainous oldland Accumulation of andesitic volcanics and sediments

tion must be assumed. Vaughan [4] and Taber [5] have described the deep trough north of Saint Croix as a graben of comparatively recent development, a fact which is indicated by the extreme youth of the escarpment off the northern coast—a drop of 13,656 feet in a horizontal distance of 5 miles.

Age Problems in the Physiographic History

General Statement

Physiographically, Porto Rico and the northern Virgin Islands, on the one hand, and Saint Croix, on the other, have developed alike until a relatively recent date. In the Virgin Islands the writer had no difficulty in identifying all the landforms which Lobeck described in the larger island. There was found, however, one erosional level which had not been differentiated on Porto Rico. It is a dissected surface intermediate in position between the upper and lower peneplanes of supposed early Tertiary erosion (compare table). In the northern Virgin Islands it stands nearly 300 feet above the submerged Middle Tertiary coastal plain, and in Saint Croix its lowest elevations are more than 200 feet above the coastal plain. In Culebra and Vieques the higher peneplane has been wholly destroyed by denudation, and the uplands of these islands, representing the intermediate level of the Virgin Islands, are likewise 300 to 400 feet higher than the Middle Tertiary marine strata. In northeastern Porto Rico, from Humacao to Cape San Juan and from Cape San Juan to Rio Piedras, an equivalent erosional level is prominent, and its relationships are similar, except that in the vicinity of Rio Piedras and Bayamon its height above the hills of the coastal plain is notably less.

Until 1926 the areas mentioned above were the only ones which the author had examined; and from the absence of decisive criteria relating the intermediate level to the coastal plain, and from the constant position of this level between Lobeck's upper and lower peneplanes, he was led to believe that it was formed in the early Tertiary, after the formation of the upper peneplane and before the development of the lower and the deposition of the coastal plain. In the course of more recent geological studies in the central and west-central part of Porto Rico, the intermediate level was found to be the most conspicuous landform, and because of its perfection of development in the barrio or township of

[4] T. W. Vaughan: Some features of the Virgin Islands of the United States. Annals of the Association of American Geographers, vol. ix, 1919, pp. 78-82.

[5] Stephen Taber: The great fault troughs of the Antilles. Journal of Geology, vol. xxx, 1922, pp. 89 and 107.

Caguana the name "Caguana peneplane" will hereafter be applied to it. In this part of the island its perfection and extent led Lobeck into assigning it to the higher peneplane, which for convenience will be designated as the Saint John peneplane—a name suggested in the study of the physiography of the Virgin Islands.[6] The error is easily understandable, for the westward rise of all the landforms brings the Saint John peneplane to such an elevation that vigorous erosion has left only isolated remnants of it. The failure to recognize an erosional level intermediate in position between the upper and lower peneplanes, moreover, gave no other alternative in correlating the erosional surfaces of central and western Porto Rico with equivalent forms in the eastern part of the island. The confusion of the Saint John and Caguana erosional levels has made necessary a restudy of both. As a result of three months of observations, which were ultimately extended over the greater part of northern and a portion of southern Porto Rico, the Caguana cycle of peneplanation has been definitely proved to postdate the deposition of the Oligocene-Miocene coastal plain. Serious doubts about the supposed early Tertiary age of the Saint John peneplane have also appeared. The writer's present conclusions, therefore, which are based on a familiarity with the entire Porto Rico-Virgin Islands area, are at such variance with those reached by Lobeck and by the author himself from studies of parts of the whole region, that a review of the landforms and their relationships must accompany the revision of the physiographic history proposed in this paper (see table, third column).

AGE OF THE SAINT JOHN PENEPLANE

The oldest landform in Porto Rico is, according to Lobeck, the upper, or Saint John, peneplane, which makes up a large part of the upland of the island. It is traceable into the northern Virgin Islands, where it is best represented in Saint John. Only a few monadnocks rise above it, prominent among them being the Luquillo Mountains and some parts of the Cordillera Central of Porto Rico. In the northern Virgin Islands the upper peneplane is approximately 1,000 feet above sealevel; in eastern Porto Rico it is 1,600 to 1,800 feet high; in the vicinity of Adjuntas its few remaining remnants are 2,600 to 2,700 feet high, and not far to the west it attains a maximum elevation of 3,000 feet. The rise from east to west is 2,000 feet in 125 miles. Its surface is at present deeply dissected, and in many places erosion has spared only a few narrow, limestone-capped, structural ridges, not unlike the hard-rock ridges of

[6] H. A. Meyerhoff: Op. cit., pt. I, fig. 17, p. 101.

the folded Appalachians. Restored, the surface displays exceeding regularity of skyline (figure 2), with a decided absence of deformation, except for the low inclination toward the east and a very slight angle of slope toward the north. The rocks beveled by the erosional surface include complexly folded Upper Cretaceous sediments, volcanics, and dioritic intrusives.

The moderate tilting which the upper peneplane has undergone contrasts decidedly with the stronger deformation of the Oligocene-Miocene coastal plain of northern Porto Rico, which dips four to six degrees toward the north. The coastal plain rests upon a deeply eroded surface of volcanics, whose residual soils and low residual hills make the contact

FIGURE 2.—*Upper, or Saint John, Peneplane*
As seen from the Caguas lowland.

between oldland rocks and Tertiary strata very irregular. If the erosional irregularities are not considered, the buried surface of the oldland rocks, which constitutes Lobeck's lower peneplane, like the coastal plain strata which rest on it, dips four to six degrees to the north. It is not likely that a dip of this magnitude is original.

Lobeck considers that the peneplane underlying the coastal plain postdated the Saint John peneplane, and in correlating the fragmentary landforms of the Virgin Islands with those of Porto Rico the writer followed the chronology which he proposed. In so dating the lower peneplane, however, several important facts were not taken into account. It was supposed that the lower erosional surface underlain by oldland (Cretaceous) rocks in eastern Porto Rico is the stripped lower peneplane, and is

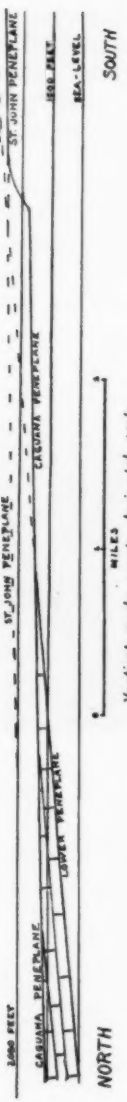

FIGURE 3.—*Diagrammatic projected Profile illustrating the Relations between the Saint John, Caguana, and lower Peneplanes*

therefore identical with that on which the coastal plain was deposited in western Porto Rico. Because of the failure to differentiate the Caguana, or intermediate, peneplane, the latter was confused with the stripped surface of the subcoastal-plain erosional surface. The result is that Lobeck's term, "lower peneplane," refers variously to the Caguana peneplane,[7] and to the stripped subcoastal-plain surface in inner lowlands,[8] as well as to the buried surface beneath the coastal plain. In consequence of this confusion, the apparent discordance between the attitudes of the subcoastal-plain erosional level and the Saint John peneplane was overlooked as a factor bearing on their respective ages. The recognition of this structural discordance raises a serious question concerning the Eocene age of the upper peneplane (compare table); for, normally, the more deformed lower peneplane, with strongly dipping coastal plain strata resting upon it, must have been formed and tilted before the less deformed upper, or Saint John, peneplane could have developed. Its age must be, accordingly, late Tertiary instead of Eocene. Admittedly the fragmentary nature of the surface forbids an unqualified assertion, especially in the absence of accurate topographic maps; but the discordance is prominent at every point from Ciales westward to Lares and beyond (figure 1), where, by projection, the subcoastal-plain peneplane on the south side of the inner lowland intersects both the Caguana and Saint John peneplanes (figure 3).

The writer is indebted to John L. Rich for emphasizing another hypothetical line of evidence which makes the supposed early Tertiary age of the Saint John peneplane less likely. Denudation

[7] A. K. Lobeck: Op. cit., fig. 8, p. 317. The tops of the hills in the figure represent the Caguana peneplane, a surface which was non-existent when the coastal plain was formed, but which was developed during late Tertiary time, beveling rocks of the coastal plain and oldland alike.

[8] Ibid., p. 316, and fig. 4, p. 305.

progresses at such a rapid rate in the tropics that an elevated peneplane in an area as small as that of the Porto Rico-Virgin islands landmass had little chance of persisting from Eocene time to the present. The great amount of recent dissection offers eloquent testimony on this point.

These considerations lead to the conviction that the higher peneplane is much younger than Lobeck and the writer thought, and that it represents a first cycle of erosion after Middle Tertiary coastal plain deposition rather than the first of several cycles before. The evidence is not final, and it is doubtful if further progress can be made toward the solution of the question before a detailed topographic survey of the island is made.

AGE OF THE LOWER PENEPLANE

It has been pointed out that the term "lower peneplane" was inadvertently applied to the Caguana peneplane in eastern Porto Rico and to the subcoastal-plain erosional surface elsewhere. In his study of the Virgin Islands, the writer endeavored to use the term for the subcoastal-plain peneplane, restricting it to the original connotation. In the following discussion it will be used only to refer to the surface of fluvial erosion which now underlies, or originally underlay, the coastal plain. In this restricted sense the lower peneplane forms little of the present surface of Porto Rico and the smaller islands, making up only the inland valley-walls of the inner lowlands. It is none the less an important feature, so far as the historical development of the island is concerned.

With regard to the age and mode of origin of the lower peneplane there can be no doubt. It is an undulating surface of moderate relief underlain by deep residual soils, buried by Middle Oligocene strata. In northwestern and north-central Porto Rico its general inclination averages five degrees to the north (figure 3); in eastern Porto Rico it apparently dips no less, but there are few unmodified exposures on which accurate observations can be made. In Saint Croix, also, it is a rolling surface, whose weathered, residual character makes its fluvial origin certain. In this southerly island, however, its dip is to the south, and the structural undulations of the coastal plain strata display slightly more irregular deformation than is apparent in Porto Rico. Broadly considered, the lower peneplane appears to be strongly arched along an east-west axis, and in northern Porto Rico the surface possesses an angle of inclination which, by projection, intersects the Saint John peneplane with definite and moderately sharp discordance. The two erosional surfaces never intersect in the field, however, because the original line of intersection was destroyed during the Caguana cycle of peneplanation

(figure 3). Like the Saint John peneplane, the subcoastal-plain level gradually rises from east to west, being wholly submerged in the Virgin Islands and attaining maximum elevations of 1,500 to 1,600 feet in the vicinity of Lares.

RELATIONSHIP OF THE LOWER EROSIONAL SURFACE TO THE SAINT JOHN PENEPLANE

The apparent intersection of the upper and lower peneplanes, if their surfaces are projected, brings up a question raised by Semmes in his study of the San Juan district of Porto Rico.[9] He suggests that the higher peneplane represents the subcoastal-plain surface, warped into horizontality away from the coast. This conjecture gains plausibility from the consideration that southern Porto Rico appears to mark rather closely an east-west axis of arching, as is indicated by the northward dip of the coastal plain in northern Porto Rico; its more moderate southward dip in southern Porto Rico, Vieques, and Saint Croix. Lobeck briefly dismisses Semmes's suggestion with the statement that there is a steep erosional escarpment between the two peneplanes, with a rise of 1,000 feet or more in the space of a few miles.[10] But the escarpment he has in mind is the steep erosional slope between the Saint John and Caguana peneplanes, about 800 feet high. At no point, so far as the writer could determine, does the higher peneplane abut directly against the subcoastal-plain peneplane, with an erosional escarpment between; but at no point in the field is there evidence for assuming that the two levels are the same. Although Semmes's hypothesis is unproved, Lobeck's point does not disprove it, and it must be included among the possibilities.

The relationship between the lower and Saint John peneplanes has thus been interpreted in three ways:

(1) The higher surface may be older than the lower and must, consequently, be Eocene in age, as Lobeck postulates. The explanation disregards the discordance of their surface structures and the unlikelihood that an erosional surface of high relief and elevation could endure from Eocene to the present.

(2) The higher surface may be the flattened extension of the lower, its angle of slope decreasing as it approaches an axis of arching near the south coast of Porto Rico. This in substance is Semmes's idea, but it disregards, also, the small chance that such a surface, where it is not

[9] D. R. Semmes: Geology of the San Juan district. Scientific Survey of Porto Rico and the Virgin Islands. New York Academy of Sciences, vol. 1, pt. 1, 1919, pp. 40 and 50-51.

[10] A. K. Lobeck: Op. cit., p. 316.

buried beneath protecting coastal plain materials, could persist since early Tertiary time.

(3) The higher peneplane may be younger than the lower and may be post-Miocene in age. This theory accounts for the parallelism of the Saint John and Caguana peneplanes and their mutual discordance with the lower peneplane, and overcomes the difficulty of accounting for the persistence of the higher level by assigning to it a later age. Although the writer inclines toward this view, admittedly it must await the further proof which detailed topographic mapping and accurate profiles will provide.

AGE OF THE CAGUANA PENEPLANE

Concerning the relationships of the intermediate peneplane which was found by the writer to be marginal to the Saint John peneplane in all the Virgin Islands, Culebra, and Vieques,[11] as well as in Porto Rico, there is now no doubt. Abundant proof of its age may be found in the Arecibo and eastern Lares districts of north-central Porto Rico. The facts will be set forth in brief detail.

In the north-central and northwestern portions of Porto Rico the Middle Tertiary coastal plain attains its maximum width, about fourteen miles, and its maximum elevation, approximately 1,500 to 1,600 feet. Only a few isolated pepinos[12] rise to 1,700 feet. The limestones composing it dip about five degrees to the north, but the present erosional surface dips northward at a much lower angle. Disregarding the cuestas, lowlands, and other features of recent dissection, the surface of the limestones slopes uniformly from 1,600 feet at Lares to 200 or 300 feet at Hatillo—a drop of 100 feet per mile. Elsewhere in the Arecibo district the surface slope is the same, averaging one to one and one-quarter degrees. Eastward the maximum elevations at the inner edge of the coastal plain gradually decrease. In the vicinity of Ciales and Morovis, for instance, the Middle Tertiary cuesta which overlooks the inner lowland rises little over 1,000 feet, but the surface slope remains constant. The difference in angle between surface slope and structural dip causes progressively younger coastal plain strata to appear from south to north. The section begins with the San Sabastian shale and the Lares limestone

[11] H. A. Meyerhoff: Op. cit., pt. 1, pp. 103-107; pt. 2, pp. 153-156, and 184-192.

[12] The word "pepino" (cucumber) is a local term applied to the limestone buttes or erosional pillars developed in two of the coastal plain formations by underground solution and surface caving. In his reconnaissance work in Porto Rico for the New York Academy of Sciences, C. P. Berkey applied the name "haystack," a term appropriately descriptive of their shape. In dimensions they range from haystack size to clusters of huge pillars, each 100 or 150 yards in diameter and 200 to 500 feet in height.

of Middle Oligocene age at the inner lowland, crosses the Cibao (Middle Oligocene) and the Los Puertos (Upper Oligocene) limestones, and terminates with the Quebradillas limestone (Middle Miocene) [13] at the coast. There is no possibility that the planed surfaces of these formations represent the initial surfaces of deposition. Their old dissection in a first cycle of erosion, during which cuestas and lowlands were formed and subdued, and the second cycle of solution and youthful denudation which they are now undergoing preclude that possibility. The even skyline which bevels these Tertiary formations must, in short, represent an upraised peneplane of fluvial denudation. The conclusion is confirmed by every line of field evidence.

Although theoretically the coastal plain is composed of less resistant materials than the complex Cretaceous oldland of the central portion of the island, it would be unique if the cycle of peneplanation which beveled them had had no effect on the oldland. The fact is, the Lares, Los Puertos, and the lower portion of the Cibao limestones, though readily dissolved, offer more effective resistance to surface run-off than the andesitic volcanics and dioritic intrusives which compose much of the interior. In the interior many of the highest areas are being protected from rapid erosion by caps of Cretaceous limestone. There is thus no reason why the folded Cretaceous rocks should have been immune to subærial attack during the erosion cycle which beveled the coastal plain. It is not surprising, therefore, that in the Arecibo district this erosion cycle—the Caguana—proved to be the most important one in molding the surface forms on the oldland as well as on the coastal plain. And elsewhere in the island its importance is but little less.

The erosional surface developed during this cycle on the oldland is continuous with the contemporaneous surface formed on the coastal plain, although the one is generally separated from the other by an inner lowland, now youthfully incised. Projection of the surface across the inner lowland shows that they coincide both in elevation and amount of seaward slope (figure 4), suggestive of a development analogous to that of the Atlantic coastal plain and the Piedmont. Along the Lares-Yauco road the northern edge of the Caguana peneplane begins at 1,700 to 1,800 feet on the oldland about three miles south of Lares and gradually

[13] The ages of the coastal plain strata were first determined by Bela Hubbard. (Geology of the Lares District, Scientific Survey of Porto Rico and the Virgin Islands, New York Academy of Sciences, vol. ii, pt. 1, tables 3 and 8.) Hubbard correlates the Quebradillas limestone with the Bowden marl of Jamaica and dates both as Upper Oligocene. Maury and Vaughan both agree with the correlation, but consider the Bowden and Quebradillas as Miocene in age.

rises southward to elevations of 2,200 feet or slightly more. Its surface becomes broken by an increasing number of monadnocks whose summits approximate the level of the Saint John peneplane. It ends in an erosional escarpment, 700 to 800 feet high, which brings the country to the level of the Saint John peneplane in a ridge, the western part of the Cordillera Central, which serves as the island's drainage divide. Except for a few isolated peaks which rise with outstanding topographic unconformity with its comparatively even crest, little of this ridge can be considered as rising above the level of the higher peneplane, as is stated by Lobeck and as is indicated in his physiographic map.[14] The actual relationships are illustrated diagrammatically in the accompanying block diagram (figure 5).

FIGURE 4.—*The Caguana Peneplane*

The view is northwest from a point about 6 miles south of Ciales. The skyline on the left is made of the elevated Tertiary coastal plain; that on the right by complex Cretaceous sediments and volcanics. In the center both overlap.

The perfection of the Caguana peneplane over extensive areas of northern Porto Rico has led to a consideration of an origin by marine planation rather than by subaerial peneplanation. The inefficacy of marine planation in tropical waters has already been pointed out by the writer in a previous paper;[15] but, putting aside theoretical generalities of this nature, proofs of the fluvial character of the Caguana peneplane are numerous:

(1) The entrenched meanders in the oldland along many of the streams, particularly the Rio Caonillas (figure 6) and Rio Grande de

[14] A. K. Lobeck: Op. cit., p. 315, and map.
[15] H. A. Meyerhoff: Op. cit., pt. 1, pp. 115-116; pt. 2, p. 184.

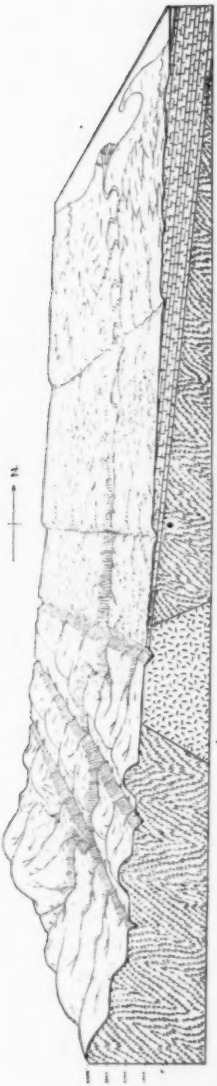

FIGURE 5.—*Generalized physiographic Section across the Arecibo District*

Loiza, are plainly related to old-age meanders initially developed during the Caguana cycle.

(2) The gradual change in character of the Caguana level southward, from a peneplane near the coast to an old erosional surface and, finally, at the base of the Cordillera Central, to a surface in late maturity, is characteristic of the headward peneplanation achieved by river systems. In the central portion of the island the erosional surface is represented by broad, old valleys, separated by structural ridges, usually limestone-capped, rising to the elevation of the higher peneplane. Comparison with the Appalachian ridge and valley topography is not only invited from features of dissection, but is forced by the fact that, like the Appalachian valleys, the Porto Rican valleys are now dissected by youthfully incised river gorges. The geologic structure of central Porto Rico is too complex, and the rocks are too nearly alike in their ability to resist erosion, however, for ridge and valley topography to be dominant.

(3) Notwithstanding the apparent perfection of the coastal portion of the Caguana peneplane, its surface has imperfections that are plainly of fluvial origin. With local exceptions, the main rivers which originate on the oldland flow northward across the coastal plain in comparatively straight, consequent courses. In the Tertiary area most of the tributaries are subsequent, flowing at the bases of cuestas in broad lowlands, which obviously existed before the present cycle of entrenchment. Between the Lares limestone cuesta and the oldland there is a persistent inner lowland

which is drained successively from east to west by rejuvenated tributaries of the La Plata, Manati, Arecibo, Tañamá, Camuy, and Guajataca rivers, while the course of Rio Culebrinas follows the inner lowland westward to the sea. Pronounced lowlands and cuestas were developed and reduced, but not completely leveled during the Caguana cycle, at the contacts between the Cibao and Lares limestones and between the Los Puertos and Cibao formations; minor subsequent lowlands were excavated elsewhere.

(4) Isolated pepino hills in the Lares and Los Puertos formations and in the basal beds of the Cibao limestone rise 100 to 200 feet above the

FIGURE 6.—*Entrenched Meander of the Rio Caonillas between Jayuya and Utuado*

average elevation of the Caguana peneplane as monadnocks which marine planation would have leveled.

The exact age of the Caguana peneplane is problematical, and the writer's interpretation may need revision in the future, when study can be based on accurate profiles from careful topographic surveys. Interpretation of its age is contingent on the age of the higher peneplane—a question which, as pointed out, can not be regarded as settled. Not only do interpretations depend upon further topographic surveys, but also on a fuller knowledge of the diastrophic history of the Greater Antilles than is available at the present time. The significant fact to be taken into account is the rapidity with which peneplanation can be accomplished in the tropics. The Pacific Border physiographic province in California has undergone two cycles of peneplanation since the Pliocene, according

to John L. Rich.[16] From such considerations assignment of both the Saint John and Caguana peneplanes of Porto Rico and the Virgin Islands to the periods since the formation of the youngest (Miocene) coastal plain deposits makes no demand upon the impossible. In fact, the implications of Lobeck's and the writer's previous works, namely, that the processes of denudation in operation since Middle Miocene time have succeeded only in effecting the youthful to mature dissection of the higher peneplane and the coastal plain, greatly strain the bounds of probability. They demand an accounting of geologic time which can not be given. It seems much more probable from theoretical considerations of the geologic time involved, as well as from all lines of field evidence, that both the Saint John and Caguana peneplanes postdate coastal plain deposition. If this is the case, the higher peneplane is certainly not older than late Miocene in development, and the Caguana cycle of peneplanation was probably interrupted at the close of the Pliocene. The present cycle of youthful dissection is thus entirely post-Pliocene, being comparable in magnitude to the Quaternary dissection which has occurred in the Raton section of the Great Plains,[17] and elsewhere in the western United States.

Bearing of the Age of the Caguana Peneplane on the Date of Antillean Block-faulting

The Caguana peneplane attains its maximum development in northern Porto Rico, where in places it is 15 to 20 miles broad, extending even to the drainage divide at a point along the highway that enters Jayuya from the west. Its extent is less, but it is never absent in the eastern and northeastern parts of the island. In the small amount of time which was available for work on the south side of the island, the writer obtained the impression that the "rugged foothill belt" of Lobeck's report represents the dissected Caguana peneplane, but additional field observation will be necessary to prove this tentative correlation. In general, of all the landforms in Porto Rico the Caguana peneplane appears to be the one invariably present, and in many localities it is areally the most important. It extends also into Culebra and Vieques, where it forms the uplands; into the northern Virgin Islands, where, though fragmentary, it is always present; into Saint Croix, where the uplands are referable to the Caguana cycle.

During this late Tertiary erosion cycle Saint Croix was physically attached to Porto Rico and the northern Virgin Islands. The faulting

[16] Personal communication.

[17] According to R. F. Collins, who is engaged in a geological survey of Union County, in northeastern New Mexico.

which caused the isolation of Saint Croix through the formation of the Anegada trough [18] postdated the Caguana cycle and is thus post-Pliocene. In his previous work [19] the writer was content with less evidence than has since been accumulated to suggest a late Pliocene or early Pleistocene date for the block-faulting which occurred. The identification and dating of the Caguana peneplane now makes it possible to assign a more exact and somewhat later date to the beginning of the diastrophic movement.

The Caguana peneplane was raised at the close of the Pliocene. The movement was differential, 2,000 feet in western Porto Rico, 500 feet in

FIGURE 7.—*Young Fault-Scarp along the north Coast of Saint Croix*
View was taken from Ham Bluff

the northern Virgin Islands, 800 feet in Saint Croix. Partial denudation followed in the Pleistocene. The coastal plain in the Virgin Islands has been extensively excavated, and deep valleys and lowlands have been incised into the oldland in all the islands. After this erosional work was partly accomplished the northern Virgin Islands, Culebra, and Vieques, were drowned 175 to 200 feet, and Saint Croix apparently shared in the submergence. The Saint Croix landmass shows features of fluvial dissection comparable to those of the northern islands over its entire surface, except along the northwestern shoreline. The latter section of its coastline is a young escarpment, much of which shows no drainage adjustments to the present outline of the island (figure 7). A few short, steep

[18] Stephen Taber: Op. cit., pp. 91, 107-108, and Plate I.
[19] H. A. Meyerhoff: Op. cit., pt. 2, 1927, p. 216, cf. p. 148.

ravines, averaging less than half a mile in length, extend from the shoreline southward into the oldland, but the balance of the drainage flows to the south and west coasts. The drainage divide is thus extremely asymmetric, and in this particular differs markedly from the eastern part of Saint Croix, where drainage systems show subequal development on both sides of the island. The escarpment forming the northwestern coast has been traced by means of soundings to depths of 13,000 feet without appreciable change in angle of slope.[20] As pointed out by Vaughan and Taber, the fault-scrap, which has a 37 to 45 degree angle of slope that shows little subaerial modification above the water-line, is in extreme youth. It has been affected by two comparatively recent geological events: a narrow, wave-cut terrace was cut into it and has since been submerged about 25 feet.[21] The freedom of the scarp from Pleistocene dissection and its modification by wave-cutting and submergence in recent time serve to date the inception of the faulting as the closing Pleistocene or the beginning of the Recent. As Taber suggests from seismic data, minor movements are even yet occurring along this fault-plane.[22]

The size and shape of the land area which foundered as a result of the movement are conjectural, but the steep coast and narrow platform off southeastern Porto Rico between Yabucoa and Guayama are features which suggest a point of attachment of the former landmass. Soundings between Saint Croix and Porto Rico are so few that no further opinion can be advanced.

The writer's field experience among the Greater Antilles has been limited to Porto Rico and the Virgin Islands, and to a brief cruise along the northern coast of Haiti and the Santiago coast of southeastern Cuba. The slender, rock-walled channel, 1,400 to 3,750 feet deep, between Tortuga Island and northwestern Haiti, and the precipitous mountain shoreline of southeastern Cuba, which drops off into depths of more than 6,000 feet within three miles of the shoreline, and a maximum of 17,000 feet about 15 or 20 miles off the coast, appear to be due to faulting no less recent than that which affected Saint Croix. It seems within the bounds of probability that the formation of the entire Bartlett trough, which extends between Cuba and Jamaica eastward into the Gulf of Gonaive, Haiti, began in the closing Pleistocene or early Holocene. A similar date may apply to the formation of the Brownson trough, al-

[20] T. W. Vaughan: Op. cit.
Stephen Taber: Op. cit., p. 107.
[21] H. A. Meyerhoff: Op. cit., pt. 2, pp. 170 and 174.
[22] Stephen Taber: Op. cit., p. 108.

though the evidence is less conclusive. This opinion, so far as it concerns the Bartlett and Brownson troughs, needs further confirmation from field data and chart study.

Summary

A review of the landforms of Porto Rico and the Virgin Islands shows that earlier physiographic studies erred in assigning none of the erosional surfaces to the late Tertiary. In fact, it is doubtful if any of the peneplanes except the one underlying the Middle Oligocene coastal plain strata can be referred to the early Tertiary. The higher peneplane of Lobeck—the Saint John peneplane of this paper—may be late Miocene in age; the intermediate, or Caguana, peneplane of the author is unquestionably closing Pliocene. As the latter peneplane was developed, upraised, and considerably dissected before the block-faulting occurred which formed the Anegada trough and separated Saint Croix from the northern islands, the date of faulting can be accurately fixed as closing Pleistocene or early Holocene. The extreme youth of other larger fault-scarps bounding the Bartlett trough in Haiti and Cuba argues strongly for an origin simultaneous with the formation of the Anegada trough. If all the troughs bounded by these east-west faults were formed contemporaneously, as appears to be the case, the close of the Pleistocene and the Holocene must rank as one of the most important epochs in the diastrophic history of the Antillean region.

Acknowledgments

The writer is indebted to Miss Louise Kingsley for drawing the block diagram reproduced in figure 5 and to Prof. Isabel F. Smith for valued suggestions and criticisms of the form and expression of this paper. Its substance has benefited from discussion of some of its points with Prof. A. K. Lobeck and Dr. John L. Rich. To the New York Academy of Sciences the writer owes especial thanks for the opportunity to make the field studies on which this work has been based, and to Dr. N. L. Britton for permission to publish these physiographic results in advance of the report on the geology of the Arecibo district of Porto Rico. In the fieldwork and preparation of the paper the author has been ably assisted by Mrs. Meyerhoff.

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STEEP SUBSURFACE FOLDS VERSUS FAULTS[1]

BY CHARLES T. KIRK AND T. E. WEIRICH

(Presented before the Geological Society December 29, 1926)

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INTRODUCTION

Subsurface geology is peculiarly different from other phases of the science because the evidence is frequently so scant that conclusions drawn from a series of known facts may differ widely. This is especially true in the interpretation of the attitude of beds below an unconformable contact wherein such additional factors as divergence of strata, steep folding, or faulting of beds may be present.

LOCALITY AND STRATIGRAPHY

The present paper depends on stratigraphic data obtained from logs of oil wells drilled 4,000 or more feet deep, near the eastern border of the "Red Beds," in north central Oklahoma. Because of some 25 feet of mantle rock, this nearly level region is remarkable for its lack of evidences of anticlinal folding at the surface. From the surface downward 1,000 feet of the geologic section is Permian, lying conformably upon 3,000 feet

[1] Manuscript received by the Secretary of the Society August 8, 1927.

of Pennsylvanian, while the Mississippian rocks ("Mississippian lime" of drillers[2] and the underlying Chattanooga shale) are commonly absent on the crests of anticlines, leaving unconformable contacts with Ordovician rocks, as shown in cross-sections in figures 2, 3, and 5.

Evidences of Diastrophism

The accompanying cross-sections (figures 2, 3, 5, 7) include only the essentials of a post-Mississippian unconformity and are drawn, as mentioned, without the usual vertical distortion, so as not to exaggerate the moderate degree of folding (chiefly compaction) about the "buried hills."[3]

Structural Provinces

The region herein discussed is remote from the Ozark Mountains, the long, sinuous folds and faults of which extend into eastern Oklahoma. It is also clearly removed from the immediate influences of the Arbuckle-Wichita Mountains. It is, however, in trend or parallel with the Nemaha Mountains of Nebraska and Kansas and the habits of its folds are similar to these, as discussed by Powers[3]—that is, in north central Oklahoma the typical dome or short anticline is characterized by steep eastward dips, as contrasted with the dips in other directions, and the anticlines over these buried hills are probably mainly the results of local vertical compacting of sediments rather than of regional horizontal stresses.[4]

Methods of Presenting Problem

The numerous cases here presented, by means of undistorted cross-sections, are found in a region where the strata are normally so nearly flat that geologists habitually measure their warps in feet per mile and represent the geologic cross-section, even where steeply folded, on a sometimes needlessly exaggerated vertical scale.

The writers are of the opinion that, wherever possible, true rather than exaggerated cross-sections should be constructed. Untrue cross-sections produce unnatural distortion of actual conditions to such an extent that in some instances one may be inclined to draw illogical conclusions. If,

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[2] Other local oil-field terms used, named in order downward, are: "Layton sand," a mid-Pennsylvanian sandstone very productive of oil, in Cushing field of Oklahoma; "Big lime," of Pawnee-Altamont age; "Oswego lime," equivalent to Fort Scott or Claremore limestone, sandy and productive of oil, in Cushing field and elsewhere; "Wilcox sand," of Tyner, Ordovician, age.

[3] Sidney Powers: Econ. Geol., vol. xvii, no. 4, June-July, 1912, pp. 237-238.

[4] Eliot Blackwelder: "The origin of central Kansas oil domes." Bull. Am. Assoc. Petroleum Geologists, vol. 4, 1920, pp. 89-94.

as in most publications, the vertical map scale used is greater per linear field unit than is the horizontal scale, then among other distortions the strata will appear to be dipping at a proportionately higher rate. Indeed, in areas within the region of southern Kansas and northern Oklahoma, where comparatively steep dips are present, an exaggerated cross-section

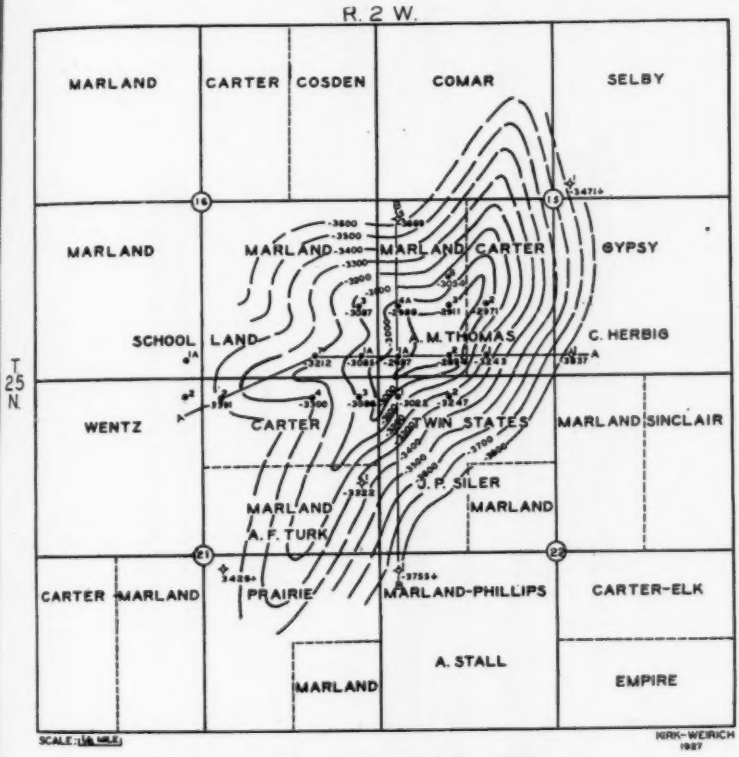


FIGURE 1.—*Thomas Field, Kay County, Oklahoma*

Contours based on upper surface of Wilcox sand; contour interval, 100 feet.

inclines the strata at such an angle as to suggest faulting; and faulting appears substantiated by such other resultant untrue factors as apparent changes in thickness of strata and extremely serrated buried topography.[5] One may thus lug in additional factors to further a premature theory of

[5] A. W. Grabau: Textbook of Geol., part II, Hist. Geol., pp. 25-26. D. C. Heath Co., 1921.

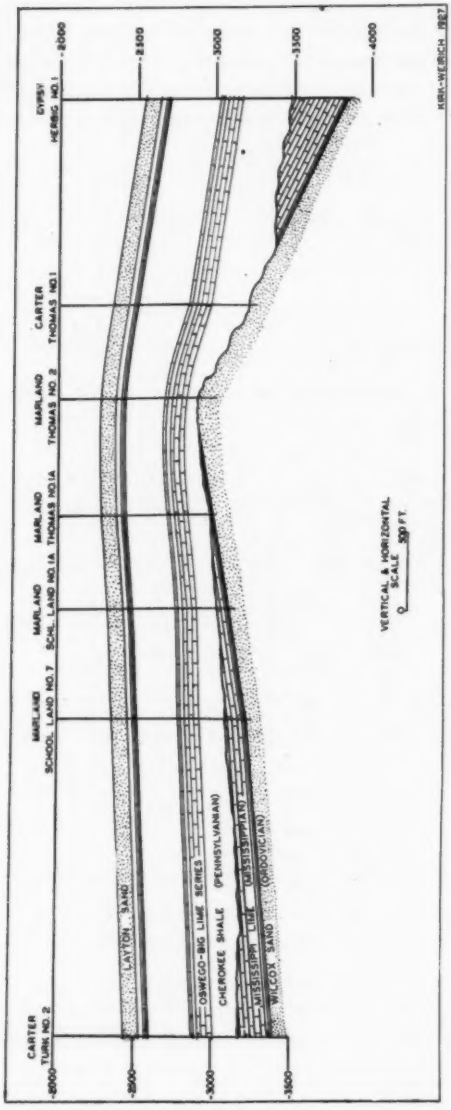


FIGURE 2.—*East-west Cross-section AA of Thomas Field*
Township 25 north, range 2 west, Kay County, Oklahoma.

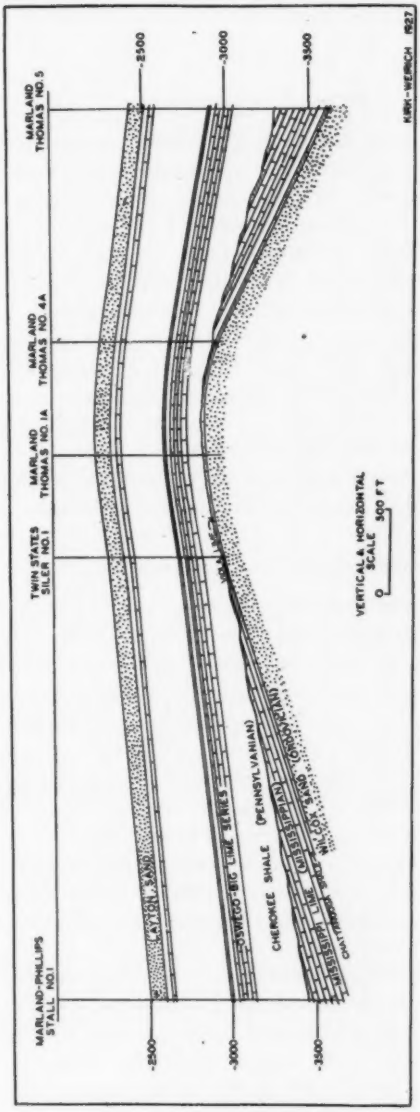


FIGURE 3.—*North-south Cross-section BB of Thomas Field*
Township 25 north, range 2 west, Kay County, Oklahoma.

faulting where an undistorted cross-section would indicate merely steeply dipping strata.

Typical Cases

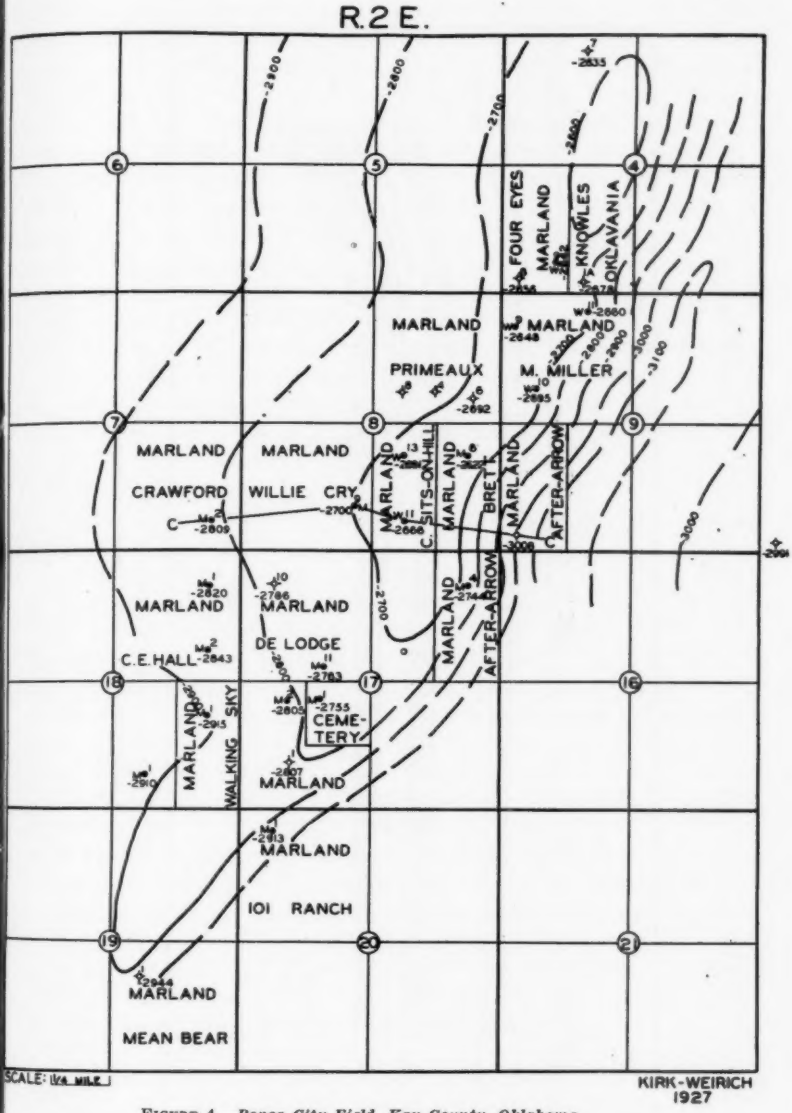
General Statement

The Thomas oil field of Kay County, Oklahoma, located in the central part of township 25 north, range 2 west, furnishes a pertinent example of possible misinterpretation. The field occurs on an anticline (figure 1) lying along a projected southward extension of the buried Nemaha Mountains, or "Granite Ridge," trending through certain oil fields in Oklahoma north of the Thomas field, as the Retta field, in township 26 north, range 2 west, and the fields in township 27 north, range 1 west; townships 28 and 29 north, range 1 east, and probably connecting with the Garber field (figure 6) to the south, in township 22 north, ranges 3 and 4 west, Garfield County, Oklahoma. In general this group of folds, to the north of the Thomas anticline, has a direction north 10 degrees east; therefore we may expect the anticlinal axis of the Thomas field to assume this general direction. Contoured on strata below the Mississippian-Pennsylvanian unconformity, the anticline does assume this normal orientation (figure 1).

Structural Considerations

The pre-Pennsylvanian strata on the east flank of the Thomas anticline are consistently dipping at a rate of 25 degrees. This fact is borne out by three wells aligned in an east-west position on this portion of the fold. Projection westward and upward of the upper surface of the Wilcox sand at its known rate of dip, as established between Gypsy-Herbig number 1 dry hole and Carter-Thomas well number 2, will place the top of that bed at almost exactly the point where it was encountered in Marland-Thomas number 2 (figure 1, south side section 15, township 25 north, range 2 west), so that the rate of dip eastward along the three points of control remains unchanged (figure 2). Thus, to assume a fault between Marland-Thomas number 2 and Carter-Thomas number 2, one must from the same line of reasoning, place a fault between Carter-Thomas number 2 and Gypsy-Herbig number 1.

Comparing the graphic logs of the three wells side by side, the geologist is impressed by the great divergence of Cherokee strata (below the "Oswego lime") proceeding basinward. The thought of the possible existence of a fault at once seems a likelihood. The writers believe, however, that, to assume a fault in this field, it is necessary, under the conditions and facts known, to assume that the highest of the three wells struc-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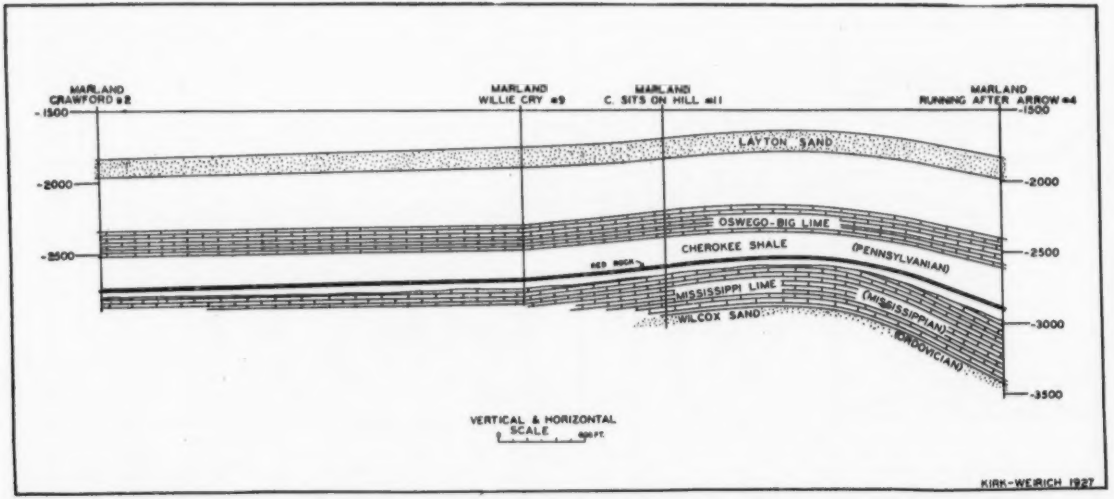

FIGURE 5.—*East-west Cross-section CC, Ponca City Field*
Township 25 north, range 2 east, Kay County, Oklahoma.

turally must have encountered the Wilcox sand near the point of its buried escarpment—that is, on the upthrown or western, side. Again, the thin measure of the overlying Cherokee shale on the assumed fault-scarp, compared to its greater thickness on the adjacent hypothetical downthrown side, should have caused faulting of all the beds overlying the buried escarpment. Moreover, this general estimate, checked against careful computations by an earlier writer,[6] with consideration of at least four thousand feet of overload, discloses that the overlying Permo-Pennsylvanian rocks must also fault; and, following this logical line of reasoning, we would expect the strata at the surface at least to assume a steeply inclined attitude immediately overlying the buried fault-scarp. As an unfaulted anticline, the Thomas structure is, therefore, in accord with the rules of overload. Deposition of the Cherokee shale and sandstone after truncation of the "Mississippi lime" and older formations would normally be greater in thickness away from the buried hill rather than immediately overlying it. Compaction of the uneven thickness of early Pennsylvanian sediments by overload would simply cause this blanket of incompetent sediments to fit more snugly about the hill—that is, reduce the basinward divergence. These conditions are analogous to those on the Cushing anticline.[7]

It is an uncommon assumption that heavily loaded rocks, whether shale or the more brittle limestone, must fault before assuming an inclination of 25 degrees. The rate of dip on the west flank of the anticline (11 degrees) is abnormally steep, as contrasted to that within the general region, but presents no evidence of faulting. Again, the 25 degrees of measured dip on the east flank (figure 2) is not so steep as are observed cases of initial dip of deposition—up to 35 degrees—even before compaction or other distortion.

A similar instance is cited in the attitude of the rocks in the Ponca oil field (figure 4). The fold in this field has the usual greater rate of dip on the east flank than on the west. The conditions of divergence, buried unconformity, and general features are quite similar to those present in the Thomas field. At the surface, however, the rocks are dipping abruptly to the east at a comparatively high rate without faulting. As shown by a cross-section of the field (figure 5), the attitude of the geologic section from the surface downward is a steep eastward dip, with more and more divergence of section until the pre-Pennsylvanian is reached.

[6] H. D. Hedberg: Bull. Am. Assoc. Petrol. Geologists, vol. 10, November, 1926, pp. 1035-72.

[7] Frank Buttram: Okla. Geol. Survey Bull. 8.
Carl H. Beal; U. S. Geol. Survey Bull. 658.

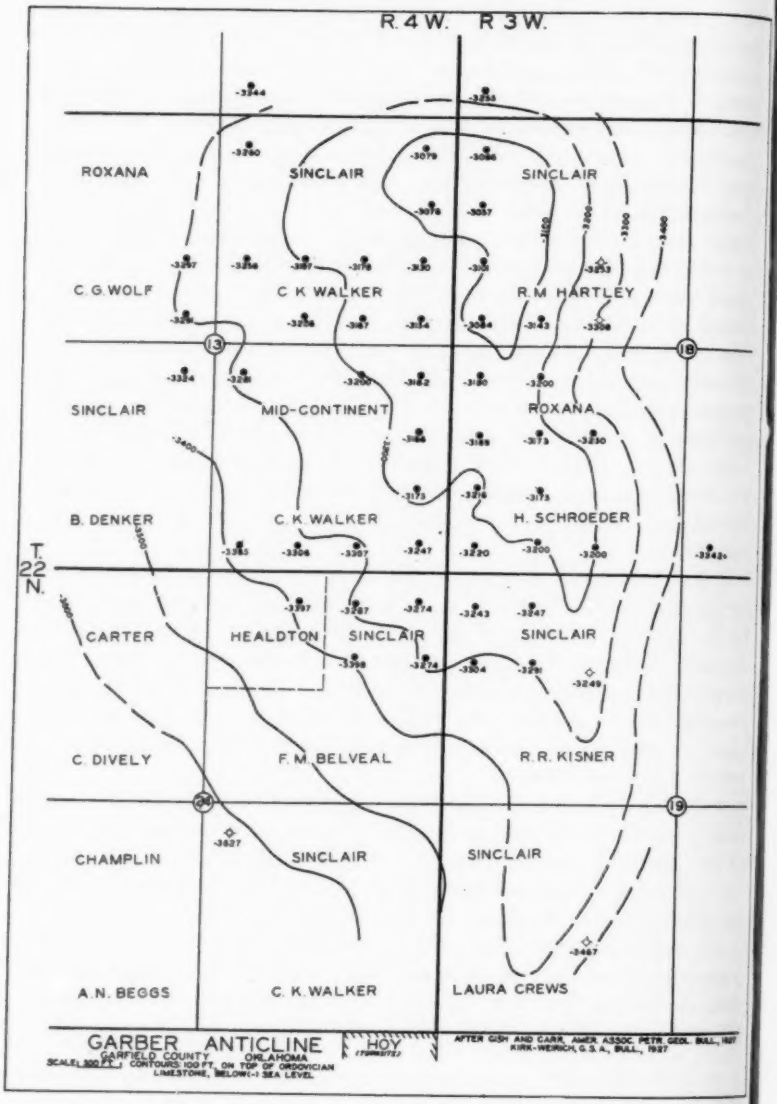

FIGURE 6.—*Garber Anticline, Garfield County, Oklahoma*

Contours: 100 feet, on top of Ordovician limestone, below (—) sealevel.

CHEMICAL CONSIDERATIONS

The presence of sulphurous water and dolomitic granules in certain upper formations in the Thomas field have been adduced as evidence that waters emanate up a fault from the pre-Wilcox "Siliceous lime," which is known to contain these substances.[8] However, siliceous lime (Arbuckle, Ordovician) is known to be in juxtaposition with the overlying Pennsylvanian rocks by unconformable contact in the Retta field, 8 miles distant, in the northeastern part of township 26 north, range 2 west, and in other fields to the north. It therefore appears quite possible that the sulphurous water may have migrated laterally (along the beds) this short distance from the Retta field or other known or unknown neighboring overlap contacts. Occurrence of dolomitic material in the Cherokee shale overlying the Wilcox sand on the east flank of the Thomas anticline may be due to its transportation by an oscillating sea from the dolomitic siliceous lime exposure on the north or elsewhere and not to an origin from the face of a fault-plane, as assumed (*ibid*).

CONCLUSIONS

The writers believe that from the evidence presented a number of faults mapped on subsurface evidences the Mid-Continent region may be based on illogical conclusions, probably inferred from cross-sections having exaggerated vertical scale, and that such supposed faults are possibly merely steeply dipping limbs of folds.

ADDENDUM

Since preparing the above the authors have noted the valuable contribution of Gish and Carr[9] on the Garber anticline, which, as above mentioned, is evidently a further southerly continuation of the Nemaha ranges into Garfield County, Oklahoma. We are permitted to adapt typical sketches therefrom, including a set of undistorted cross-sections (figures 6 and 7). By combining these cross-sections on a single sheet (figure 7), certain interesting relationships are easily observed.

Besides having a pronounced eastward surface dip, this structure also differs from others in this region in having its axial plane inclined eastward (figure 7); there is also an unusual steepening of the westward dip on the Ordovician, especially along its projection westward beyond the known closure elevation. The characteristic increasing intensity of folding with depth, which is common in the Mid-Continent fields, is easily

[8] S. K. Clark: Bull. Am. Assoc. Petrol. Geologists, vol. 10, no. 7, 1926, pp. 643-655.
[9] Forthcoming Bull. Amer. Assoc. Petroleum Geologists, 1927.

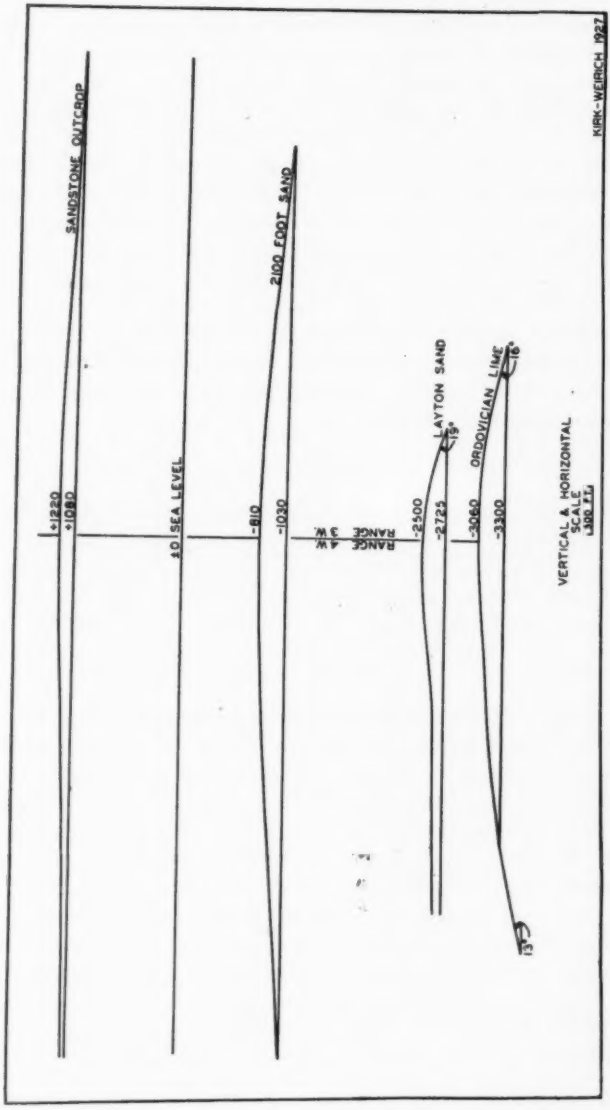

FIGURE 7.—*Cross-sections of Garber Field, Garfield County, Oklahoma*
Township 22 north, ranges 3 and 4 west.

noted by referring to the cross-sections (figure 7). The oversteepening here shown on the Layton sand is exceptional and to be expected on a lensing formation.

As observed by Gish, if faults are assumed on the east side of the relatively steep Ordovician buried hill, they must also be drawn on its west; and such faulting is easily inferred when the cross-section is given the common vertical exaggeration of 2 or 3 vertical units to 1 of horizontal.[10]

Thus, in this instance, there is set before us evidently a case of *reductio ad absurdum* as to the assumption of faulting, and the inference is drawn that this is merely another steeply dipping fold.

[10] Clark: Loc. cit., his figure 2, page 647.

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From map of Agostino Codazzi, 1864. Scale 1" = 56 miles.

OF NORTHERN COLOMBIA AND WESTERN VENEZUELA

map of Agostino Codazzi, 1864. Scale 1" = 56 miles.

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NONMARINE TERTIARY DEPOSITS OF COLOMBIA[1]

BY F. M. ANDERSON

(*Presented by title before the Society December 29, 1926*)

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[1] Manuscript received by the Secretary of the Society December 16, 1926.

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Introduction

The great basins of the Orinoco, Maracaibo, and the Rio Magdalena occupy much of the general area of northern South America. What relations may have existed among these several basins in the past, or even within the limits of the Tertiary, can only be surmised in the present state of geologic knowledge, though there are grounds for suspecting that throughout the Tertiary era all shared in the major movements of uplift and subsidence, with individual differences. It seems probable that there was intimacy, if not actual connection, between some of these basins during the early Tertiary. All seem to have had somewhat similar drainage relations to the region lying between, but to what extent each of them transgressed such land area as existed there during the Tertiary is not yet known. At the present time the high cordillera of the eastern Andes lies between or borders on these several basins.

A large part of the East Cordillera lying within the boundaries of Colombia constitutes a broad, mountainous, and much-dissected plateau region which by German authors has often been referred to as the Plateau. From this plateau the Sierra de Perija forms a northward extension, separating the drainage of the Magdalena from that of the Maracaibo, and in like manner the Sierra de Merida, extending to the northeast, divides the drainage of the latter from that of the Orinoco.

As here understood, in its broader aspects the Plateau embraces the general base on which rise many ranges, and preeminently those which align themselves along its eastern and in part its western borders. Between these border ranges and others less prominent are several important valleys of considerable altitude occupying the sites of ancient lakes. These plateau valleys extend through a distance of some 300 miles north of the latitude of 4 degrees north. The much-dissected plateau region extends farther. The geographic and geologic relations of the several major basins to the East Cordillera and to each other suggest that there is probably

much parallelism in the sequence of their Tertiary deposits, marine and nonmarine.

The basin of the Orinoco is as yet but little known, except near the coast, on the Island of Trinidad, and at the other extreme, in the mountains of its western tributaries.

In the basin of Maracaibo, as in that of the Magdalena, exploration for petroleum has brought more information, and the sequence of sedimentary deposits from the Cretaceous down to the present is better known. Their intercorrelation, however, yet remains to be wrought out, although its importance from the viewpoint of economic geology seems obvious.

Tertiary deposits are abundant in Colombia and are represented by both marine and nonmarine sediments widely spread over the country. The marine deposits are found in the coastal districts along the Pacific and the Caribbean Sea and extend inland from the latter for more than 100 miles. The nonmarine and partially marine sediments are spread along the larger valleys and among the mountains far into the interior.

The correlation of the marine, partially marine, and nonmarine deposits has not been attempted before, since but little has been known regarding them. Karsten first referred to the marine Tertiary deposits along the north coast,[2] as also to the Tertiary formations in the upper valley of the Magdalena, on the borders of the East Cordillera and also high up in the plateau valleys of the same, but he gives only meager information and makes no attempt at correlation, referring them only to the Tertiary without differentiation.

At the present the principal basis for such correlation lies in the history and development of the Andean mountain system, which in its origin and framework antedates the Tertiary. Within the limits of Colombia this system splits up into a number of diverging cordilleras, some of which have outliers along the north coast. That their principal ranges and intervening valleys had their beginning in pre-Tertiary time seems certain from the fact that the nonmarine Tertiary deposits occupy intermontane basins in both northern Colombia and in Venezuela. In Colombia these deposits extend inland along the valleys and among the mountains in a manner that suggests long and narrow inlets from the sea, leading first into estuarine and then into entirely nonmarine conditions farther in the interior of the country. Thus three distinct or partly distinct facies of deposition may be recognized, each in their proper provinces. These several facies appear to reoccur in the successive geologic series, although

[2] H. Karsten: Geologie de L'Ancienne Colombie Bolivarienne, etc. Berlin, 1886, pp. 22, etc.

as yet they are not well known and in part are not easily distinguished. At the present only a tentative attempt at correlation can be made, based chiefly on an assumed parallelism in the sequence of deposits in the marine, partially marine, and nonmarine provinces, which may later need revision.

Presumably the major events in the diastrophic history of the continental border were widespread in their effects; but in any case, where conditions permitted, sequences of strata would result in the intermontane valleys as well as on the sea margin. Epochs of subsidence which would produce marine deposits near the coast should also have formed others in the drainage outlets from the land areas—that is, in the marine inlets and in the land-locked basins as well—just as would happen under similar circumstances at the present. Although no complete account of any of these sequences of deposits in their various facies can be given at present, the outline on the opposite page has been prepared, which should serve to direct later study and discussion.

Eocene Series

General statement

The deposits of the Eocene period illustrate better than any other the three facies of deposition found in the Tertiary formations of Colombia, and in them we can easily recognize marine, estuarine, and also widely distributed terrestrial or lacustrine beds in great development.

Marine facies

The distribution, volume, and character of the marine Eocene deposits of Colombia have already been briefly discussed in a former paper,[3] in which they are shown to be widely strewn along the coastal border in the north, and to occupy the larger valleys in part, known as the low country of Colombia. West of the Magdalena and north of the limits of Antioquia, they underlie most of the region of low plains and low ranges that flank the central and western cordilleras. They fill the valleys of the Rio San Jorge, the lower valley of the Magdalena, the valley of the Rio Cesar in part and its northward continuation about Rio Hacha. They crop out also in the coast ranges west of the Sinú Valley and in the San Jeronimo range between this and the San Jorge.

Nonmarine facies (Guaduas series)

Views of other geologists.—Karsten originally described[4] the coal-

[3] F. M. Anderson: Bull. Am. Assn. Petr. Geol., vol. x, 1926, pp. 388-391.
[4] H. Karsten: Loc. cit., p. 29.

Classification of Colombian-Tertiary Deposits

Periods	Marine deposits		Estuarine deposits			Lacustrine deposits
	Magdalena lower valley	Cartagena district	Sinú River region	Magdalena, central valley	Magdalena, upper valley	Plateau region
Pliocene	Galapa group (a part)	La Popa group (a part)	Escondido group (a part)	Honda series "Upper Oponcito"	Honda series	?
Miocene	Tubera series	Turbaco series	San Antonio group (Beck)	Oponcito series	Barzalosa series	Miocene?
Oligocene	San Juan group	?	Bombo shale (Beck)	?	?	?
Eocene	Carmen-Zambrano series	Arjona series	Tofeme-Coloso series	La Paz series	Guaduas series	Guaduas series
Cretaceous	Guadalupe group	?	?	Guadalupe group	Guadalupe group	Guadalupe group

bearing Tertiary strata of the Plateau country of Colombia, first in their occurrence at Bogotá and then in the folded and faulted zone of the west border of the Plateau, in the valley of Guaduas and at neighboring points. Concerning this formation he says in part:

"In these probably Tertiary deposits which rest discordantly upon the fossiliferous sandstone (Guadalupe), I observed at Boqueron, above Bogotá, some metallic mercury, as I have said above. At the foot of Guadalupe are found here and there some thin beds of lignite intercalated. . . .

"This fine and crumbling sandstone, which outcrops at Bogotá in thick beds, takes here and there a coarser texture; there are intercalated some conglomerates and puddingstones, to which it passes entirely later; for example, upon the summits which face the Magdalena, Altos del Trigo, Guaduas, del Sarjento.

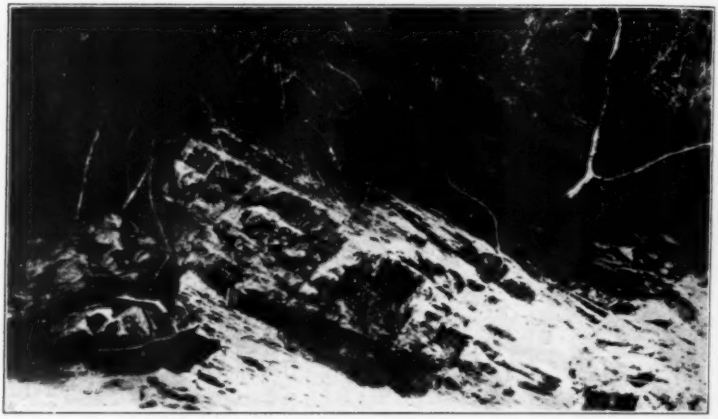

FIGURE 1.—*Westward-dipping Guaduas Beds*
Near mouth of Guaduas Creek. Photograph by K. D. White.

These sandstones rest, as a rule, upon some siliceous and argillaceous shales, in which I found scales of fishes, debris of shells and Polythalamias; for example, *Orthocerina Ewaldi* Karst. In this system of beds, which upon the west border of the Plateau of Cundinamarca everywhere forms terraces, there are found in the upper part conglomerates, the pebbles of which contain *Foraminifera* of the Upper Cretaceous; these beds thus belong to a more recent period and are, therefore, Tertiary."

Hettner did not accept this view, taking the disconformity described by Karsten as only apparent, and was disposed to regard the series as uppermost Cretaceous and gave to it the name of Guaduas beds. However, Hettner gives a more complete account [5] of both the local and gen-

[5] A. Hettner: Die Kordillere von Bogotá, etc. Peterm. Mittell., 1892, pp. 14, 15, 16.

eral sequence of strata and of their distribution along the borders of the Plateau and on its summit. After a brief description of the Guadalupe

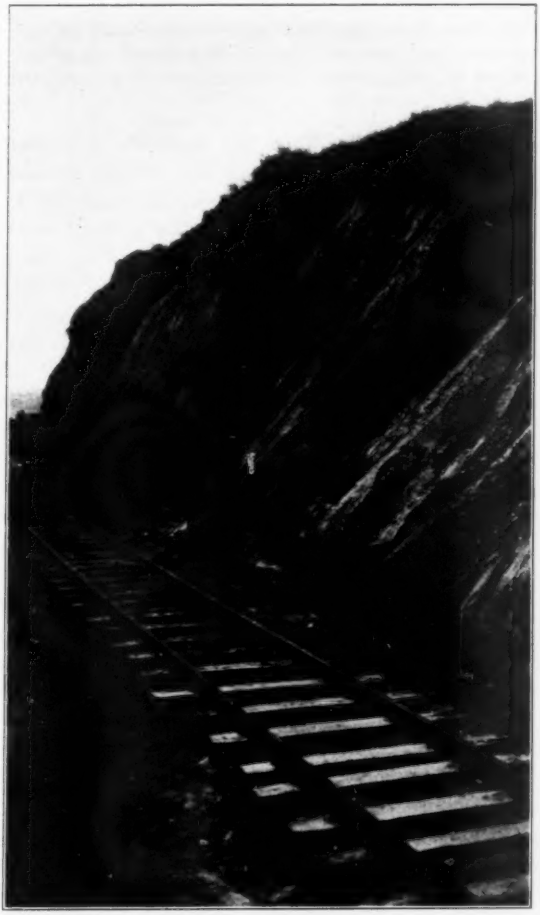

FIGURE 2.—*Guaduas Beds.*
Near Nemocon. The beds have a steep, westerly dip.

group in its occurrence on the west border of the Plateau, Hettner thus continues:

"Above this division follow the Guaduas beds, a system of mixed, peculiar yellow, red or violet, brown ironstone rocks comprising clays and interstratified

beds of coarse-grained, mostly red or dirty white sandstone, which locally changes into conglomerates. To the lower part of this stage, or to the upper beds of the Guadalupe, belong the Colombian coal, with its covering of dark clay slates.

"Other fossils than poorly preserved plant remains have not yet been found. Karsten supposed that this stage rested discordantly upon the Guadalupe stage, and therefore pronounced it to be Tertiary. I can accept this discordance as apparent only, etcetera." . . .

Distribution.—In the appendix to his paper Hettner describes many local occurrences of the Guaduas beds, as near Soacha, Zipaquira, Nemocon, La Calera, Tausa, Sesquille, Guatavita, the valley of Tenza, Choconta, Tunja, and many other places. On his geologic sketch map he shows Guaduas areas near Bucaramanga, and west of Pamplona, and along the east foot of the cordillera, near Medina and northward at Labrazagrande, Topaga, etcetera, and his description suggests the equivalency of these beds with others in the Maracaibo basin, if not their geographical connection.

The coal beds which characterize the Guaduas series Hettner believed formed a zone of transition from the Guadalupe, and he believed they would be found wherever both series occurred about the Plateau.

Stille,[6] in discussing the stratigraphic series of the East Cordillera, concurs with Hettner in regarding the Guaduas as conformable on the Guadalupe group and tentatively classes it as Cretaceous. He believed that he had identified these beds along the upper valley of the Magdalena above Giradot, in the Department of Tolima, at Dolores and neighboring places, where he stated that he found in them intercalations of porphyrite and porphyry tuffs, and that they were cut by dikes of another eruptive rock which he described as quartz porphyry. He found similar occurrences of such rocks at the western foot of the Sierra de Ocaña, where in the middle of the Guaduas series two types of eruptive rocks are noteworthy. They do not appear to belong to exactly the classes found in the Guaduas near Dolores, but are, nevertheless, interesting from the viewpoint of geologic history. Sievers,[7] after an inspection of some Guaduas beds west of Pamplona, referred them to his Cerro de Oro system, as noted by Hettner. Stille discredits this view and states in a footnote (page 295) that he sees scarcely any resemblance and believes the Cerro de Oro system to be Cretaceous, suggesting that its position must be somewhere on the boundary of Villeta and Guadalupe. Although Stille regards the Guaduas as belonging to a higher stage of the Cretaceous, he

[6] H. Stille: Geolog. Studien im Gebiete des Rio Magdalena, von Koenen Zeits., pp. 277-358.

[7] William Sievers: Keits. der Gesells. f. Erkunde, Berlin, 1888, pp. 1-158.

offers the following interesting comments (page 345), which apply to at least a part of the Guaduas group:

"In the red clays and marls of the Guaduas stage with the interpolated beds of eruptive rocks, I believe must be recognized the sediments of a somewhat detached part of the sea, in which, on account of its evident connection with the open sea, there resulted an enrichment of its salt content, and therefore a precipitation of the same, and this high salt content perhaps plays a rôle in the deposition of iron in the form of red anhydrous oxides." . . .

Most of the well-known salt deposits of the Plateau are only indirectly connected with the Guaduas beds, if at all, though the oxides of iron are characteristic of them in many places, as elsewhere explained.

The definite proof of unconformable relations of the Guaduas and the Guadalupe we owe to Dr. Robert Scheibe, who represented the Comision Cientifica Nacional at Bogotá. In his few published papers, now difficult to obtain, he made valuable contributions to the geology of the Plateau. Regarding the relations of these series, he says in part:

"To solve this problem it serves somewhat to recall the fact that in the region of Tocaima . . . there are places in which may be observed the discordant superposition (and transgression) of the basal beds of the Guaduas series (with the coal member) upon marls and Planer shales of the lower part of the Guadalupe group, which mark a position below the sandstone member of the same group. This observation at places so distant one from another indicates that this discordant superposition is a general phenomenon, and normal in our region, and that here the opinion of H. Stille is not justified, who believes that there must always be a concordant superposition of the Guaduas upon the normally developed group of the Guadalupe." . . .

In a verbal statement to the writer, Dr. Scheibe laid stress on various facts supporting this view and expressed his belief that the Guaduas series is Eocene in age, the deposits of which he thought ought to occur on the Plateau. After a careful examination of many of the nonmarine deposits, including several discussed by him, and others about Puerta Berrio, San Vincente, Honda, and other places in the upper valley of the Magdalena, the writer concurs with his views, not only regarding the relationship, but also with regard to the age of the Guaduas. No positive evidence of marine contact has been observed in any of the Guaduas deposits on the Plateau, and they are not believed to have had such, in spite of contrary views expressed by others.

Besides the areas of Guaduas on the western border of the Plateau noted by other writers, there are occurrences farther north, some in the lowlands, which seem to have escaped notice. The name Guaduas may well be applied to many deposits in districts widely distant from the type locality of this series, both on the Plateau and in the lowlands.

In the central valley of the Magdalena and at the exit of its larger tributaries from the mountains, as the Rios Carare, Colorado, Sogamoso, and Lebrija, where deltalike conditions existed, the Guaduas series, with its horizon of coal and carbonaceous beds, has been greatly developed. It is possible that the same conditions of deposition existed in the valleys of the Rio Cesar and the San Jorge, in both of which coal veins are reported, although the deposits are not so well known.

The thickness of the Guaduas deposits varies with locality. In some places the series has suffered much from denudation and in others it has been partly covered by later deposits, as at Honda, Tocaima, and on the Rio Colorado, as probably also along the western border of the upper valley of the Magdalena; so that its full thickness is not always to be seen. On the Plateau the Guaduas fills many of the local basins, where aggregates of strata attain to over 6,000 feet in thickness, as near Zipaquirá, where Scheibe's estimate is 2,000 meters. Probably the greatest accumulation of Guaduas sediments is in the central valley of the Magdalena—that is, the delta areas into which so many rivers discharged—lying between the East and Central cordilleras above El Banco, the outlet of the central valley.

This area is represented by the district of Barrancabermeja, where the Tropical Oil Company owns an extensive concession. The road from the Magdalena eastward to San Vicente crosses an enormous sequence of strata, among which the beds referred to the Guaduas by the writer include a great thickness of dusky or dark clay shales with interstratified sandstones, the exposed portions of which were estimated at more than 5,600 feet in thickness. Carbonaceous beds and veins of coal constitute a notable group near the bottom of the section. This zone of Guaduas lies between the village of Morenga and San Vicente, beyond which the Cretaceous rocks of the East Cordillera appear to have formed the shore of the Eocene inlet.

Faulting along the west foot of the East Cordillera has resulted in a succession of eastward-dipping blocks, two or more of which expose only Guaduas strata. Toward the west this zone of Guaduas is bordered and overlaid by the Oponcito series (Miocene), while eastward the road rises on the Guadalupe (Cretaceous) rocks to above 7,000 feet above the sea. As the Guaduas series is partly concealed by later deposits and its study was attended by other difficulties, no estimate of its entire volume was made, though other geologists have placed it at above 10,000 feet. It is possible, however, that such estimate included beds of Oligocene age, since, if they occur in Colombia at all, they should be found in this section also, though they were not identified. The upper part of the Guaduas

in this region is much more sandy than that part with which the coal veins are associated, near the base.

Examples of Guaduas.—While considerable information may be gathered from preceding paragraphs concerning the character and composition of the Guaduas series on the Plateau, their importance would warrant still further statements if not illustrative examples. Dr. Scheïbe gives a detailed account of the coal-bearing portions of the Guaduas in the district of San Jorge and Llanos de Animos, near Zipaquira, which he has divided into two groups which are overlaid by a third. The coal measures, forming much of the first two groups, are confined to some 625 feet, in which are various veins of coal.[8]

A more minute analysis of these strata immediately connected with the principal veins may be condensed as follows:

	Inches	Inches
Surface, black earth and debris.		
Black bituminous shales	....	7.87
Coal	....	44.50
Flagstone	3.15	45.12
Coal	13.00	21.65
Flagstone	2.75	3.15
Coal	8.26	8.66
Rock	4.70	5.90
Coal	22.44	22.84
Gray shales.		

In all there are, on the average, 7.78 feet of coal.

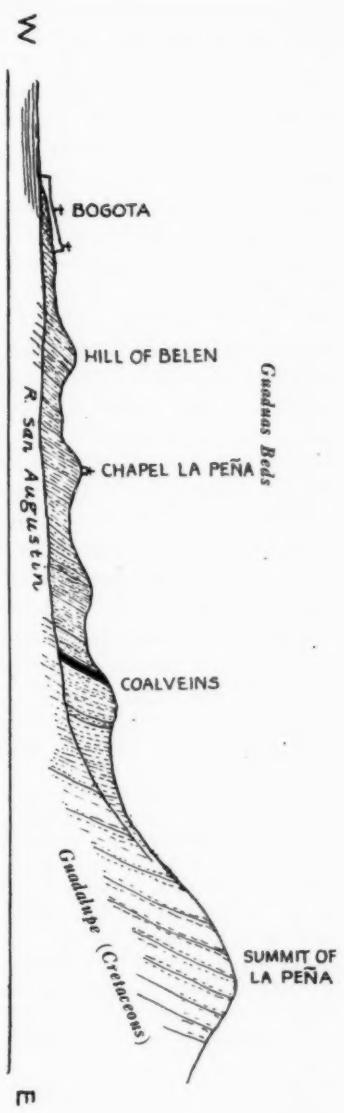

FIGURE 3.—*Section through La Peña near Bogota*
After Hettner, page 35.

[8] R. Scheïbe: Doc. de la Com. Cient., 1918, Mem. de Obr. Publ., p. 155.

The total thickness of the Guaduas strata in this district is estimated by Scheibe as not less than 2,000 meters (6,560 feet), the great mass of which is composed of sandstones and sandy shales belonging to his Group III. They are folded into a sharp syncline lying between ridges of Guadalupe strata. There is a strong lithologic resemblance of these beds to those seen in the district of the Rio Colorado and at Las Doradas. The Guaduas beds exposed about Bogotá, although not showing a complete section of the series, constitute an aggregate of nearly 3,000 feet of strata with a normal eastward dip toward the Sabana. From the base upward the series exposed consist of sandstones, followed by sandy shales and carbonaceous beds with veins of coal, sandy mudstones, clay shales, sandy shales, and fine sands. These beds exhibit a variety of colors, including dark brown, terra cotta, orange, red, violet, yellow, and dirty white, in many shades of each. The sandstones are usually micaceous and highly siliceous. Stains of iron oxides are conspicuous in all exposures, and it may be that most of the variety of color is due to some form of iron oxide. The sandstones are often loose and crumbling, never hard; those overlying the coals are composed chiefly of quartz sand of a reddish or orange color, which is often used in concrete mixtures. The rock in some of the strata shows minute scales resembling gypsum, though its identity was not determined. Some of the sandy shales are much used for bricks, tiles, and pottery, the supplies for such purposes being inexhaustible. The series continues along the foot of the range for many miles, resting in monoclinal fashion against the older rocks of the Guadalupe group forming the mountain ridge east of the city. Hettner has given a good description of the structure of these beds and his profile through La Peña is reproduced here. His description of this structure (page 33) follows:

"At the foot we find the red sandstone and clay of the Guaduas stage, beyond the chapel of La Peña white quartz sandstone (Guadalupe) outcrops under it, which from here continues up to the peak. In the highest beds are enclosed two coal veins (0.6 and 1.5 meters thick), which are separated from one another by a bed of grayish black clay shale 4.5 meters thick. In the coal mine of the gas company one can observe how the vein becomes steeper toward the east, takes a vertical attitude, and finally overturns toward the west. The same overturning can also be noticed in the sandstone of the exposures lying behind. The normally stratified lower member probably continues under the alluvial deposits of the valley. . . .

"In the Boqueron north therefrom, the gorge of the Rio San Francisco, the beds may be followed eastward up the valley bottom, with the same direction of dip; in their western part, however, we see them in the middle altitude to overturn toward the west, just as at the coal mines." . . .

Near Chapinero, a suburb of Bogotá, on the north, the same structural conditions are found, showing an overturn with steep dips toward the east, as if against the older rocks of the Guadalupe.

Coal in the Guaduas.—All of the authors who have attempted any description of the Guaduas beds have referred to their contained coal veins. Hettner mentions both coal and iron, as illustrated in the following paragraph (page 64):

"Fortunately, in the vicinity of iron there is coal. The Colombian coal belongs neither to the stone-coal nor to the European brown coal (Oligocene), but most probably to the Cretaceous formation, and of course to the transition beds between the Guadalupe and the Guaduas epochs. In spite of their very young age, they possess a character almost like stone-coal and are especially adapted to making gas."

Among the numerous localities mentioned by Hettner where coal is found in the Guaduas of the East Cordillera are Cerro de la Paz, Carare district, Nemocon, La Pradera, Samanca, and others already given. The Guaduas series near Zipaquirá is probably representative. According to Scheibe, the series is here folded into a narrow syncline, the coal area of which occupies about 12.5 million square meters, within which he calculates 34,634,730 cubic meters of coal, approximately 41.5 million metric tons. Scheibe continues:[9]

"The quality of the coal is normally good. The following data indicate the composition, on the average, of the coal from the principal vein in the present mine of Picacho:

	Per cent
Moisture	1.5
Fixed carbon	53.5
Volatile matter	38.5
Ash	6.5
	100.0

"Coke, 60 per cent; calorific power, 4,400 calories."

Age of the Guaduas.—After a study of the marine Tertiary deposits along the north coast and in the low country of Colombia, where the sequence is well known, and of the nonmarine beds of the interior, especially in the upper valley of the Magdalena, the Eocene age of the Guaduas series might well be surmised, chiefly from its stratigraphic position, with the known Guadalupe beneath and presumably Miocene strata above. There are other evidences, however, noted by other writers who have reached our conclusion, as will be shown below.

Dr. Otto Stutzer (1923), after a brief discussion of the geologic events

[9] R. Scheibe: Loc. cit.

of the Tertiary in this region, especially in the upper valley of the Magdalena, says emendingly, in a footnote (page 183):[10]

"3. Meanwhile the author was in Venezuela. He now holds the Guaduas beds as Eocene. In Venezuela coal-bearing Eocene characterized by Eocene Foraminifera lie unconformably upon the Cretaceous." . . .

In a later paper (1925)[11] Stutzer consistently regards the Guaduas beds as of Eocene age, stating that they are overlaid discordantly by the next group, the Barzalosa-Gualanday series of Scheibe. This latter discordance represents a notable time interval that may have great importance in the correlation of these formations.

While no molluscan fossils have hitherto been reported from the Guaduas beds, they have been found abundantly in the estuarine areas in the upper as well as the central valley of the Magdalena, although their character affords only corroborative aid in age determination. On the Sogamoso and the upper tributaries of the Rio Colorado, and from San Juan, Rio Seco in the upper valley, faunas have been found which include the following species:

Ampularia graduasensis, n. sp.,
Melanella magdalenensis, n. sp.,
Corbula Hettneri, n. sp.,
Cyrena Karsteni, n. sp.,
numerous plant remains, etcetera.

The material bearing these fossils is a dusky gray clay shale, with blotches and flecks of carbonaceous matter, showing also resinous scales. Veins of coal within the same series are mined not far away. Similar beds with like fauna and plant remains have been found a little to the east of Giradot, and in the same locality, according to Dr. Scheibe,[12] are minable veins of coal, and more rarely "nests of resin," or amberlike material, "in dark clay shales immediately above the worked vein."

At Cipacon, Tequendama, and Guasca, according to E. W. Berry,[13] an

[10] O. Stutzer: Zeits. d. Deut. Geol. Gesells. B. Monat., no. 11-12, p. 179.
[11] Idem: Neues Jahr. f. Min. Geol., etc. Bell., Bd. 52, p. 162.
[12] R. Scheibe: Loc. cit., 1918.
[13] E. W. Berry: Bull. Geol. Soc. Am., vol. 35, 1924, p. 782.
In a later paper (Am. Journ. Sci., Vol. X, 1925, p. 537) Dr. Berry has revised his view as to the age of these deposits, chiefly, it seems, upon the occurrence of certain plant genera in some of them which also occur in Peru in strata determined by Olsson to be Oligocene. Concerning this correlation Dr. Berry says:
"And if the coal horizons of Guadalupe and Monserrate is the same as that at the mines of Cipacon at the western margin of the Sabana, then the age is almost certainly Oligocene, for the latter contain fruits of Saccoglottis, Vantanea, and Anacardium common to the Oligocene of northwestern Peru, where the age determination rests upon abundant marine faunas." . . .
The results of the work by A. A. Olsson referred to have not been published; but, without calling its authenticity in question, it would seem to the writer that plant genera in so limited number may not be sufficient grounds for such correlation, and it is more in accord with known facts to still regard the Colombian beds as of Eocene age, and to reserve any revision of their correlation until more conclusive evidence has been supplied.

upper Eocene flora has been found, and these localities or their deposits, in addition to being coal-bearing, are almost continuous with those at Guaduas, Bogotá, and other places before mentioned, while the coal, carbonaceous beds, and brackish water mollusca all serve to confirm their identity with the La Paz beds at Las Doradas, Rio Colorado, Rio Sogamoso, and other places along the west foot of the East Cordillera.

Altitude relations.—The three distinct facies of Eocene deposition for the most part are now found at different elevations above the sea. Most of the purely marine sediments still lie near or rarely more than 1,000 feet above sealevel. In some cases, as near El Carmen, Bolivar, and in some of the ranges west of the Sinú Valley, they rise to 800 feet or a little more, as in the Cerros de Las Palomas.

In the estuarine areas of the central and upper valleys of the Magdalena they rise to much higher levels, where brackish water faunas have been found, as at San Juan, Rio Seco, 4,084 feet, and they range from the floor of the valley (1,000 feet) up to this altitude or higher.

In the purely nonmarine districts of the Plateau they range to altitudes of over 9,000 feet, as shown in the following list of localities, all of which are fairly well known. The data are taken from official and partly official sources and are believed to be trustworthy:

Estuarine Conditions

	Feet		Feet
Giradot	1,082	Tocaima	1,414
Guaduas	3,366	San Juan	4,084
Dolores (?)	5,039	Tequendama (?)	8,000

Lacustrine Conditions

	Feet		Feet
Cipacon (?)	8,670	Bogotá	8,800
Zipaquira	8,700	Sesquilé	8,705
Guasca	8,704	Choconta	8,730
Funja	9,250	Tausa	9,164

Some of the occurrences of Guaduas may be even higher, as on the paramo east of Bogotá, where beds of the same character are found at elevations above 10,000 feet. On the east slope of the East Cordillera, according to Hettner, the Guaduas occurs at Medina, 2,000 feet, and at other places somewhat higher.

Structures.—The structures of the Guaduas beds reflect the diastrophic history of the continental border to a great degree, not only since deposition, but to a certain extent before. In all their situations, as far as known, the Guaduas beds are inclosed in basins or depressions among ranges of older rocks and have suffered folding and faulting, some of

which is excessive, but usually producing synclines coextensive with the basin itself. On the borders of such basins the strata often stand at angles of 40 to 60 degrees, although elsewhere they are quite flat. On the Plateau a long line of such basins filled with Guaduas deposits may be followed from near Fusagasugá northeasterly to Duitama, on an upper tributary of the Sogamoso, in all of which synclinal structures prevail. The same is true also of the smaller lateral basins, as that of the ranchos San Jorge and Llano de Animas, described by Dr. Scheibe. This chain of deposits in the high Andes was doubtless originally connected by way of Fusagasugá and the basin of Melgar with the Guaduas deposits of the upper valley of the Magdalena, which rise on its borders to considerable elevation.

In general the west slope of the Plateau is a folded and faulted zone extending north and south and crossing obliquely other structural lines. Segments of the Guaduas are found, therefore, at various elevations between the Magdalena valley floor and the valleys of the Plateau. Farther north, in the central valley of the Magdalena, similar facts are noted by Hettner, and perhaps they can be followed into the valley of the Rio Cesar, beyond which Stille would continue the faulting.

While Guaduas deposits east of the Magdalena are folded into a long and narrow syncline extending northward from near Giradot along the Rio Seco, Rio Guaduas, and Rio Negro, in other places they are greatly faulted, as west of Pandi, Cipacon, and Utica, and even more in the region west of San Vicente and on the lower Sogamoso, as well as farther north. Various eruptive rocks have been described as being associated with the Guaduas in different parts of the country, though they are not abundant. According to Stille,[14] sheets of porphyry tuffs have been interpolated in the Guaduas beds, which have later been cut by dikes of quartz porphyry. The historical significance of these eruptive rocks in the Guaduas series is highly interesting, as perhaps marking the beginning of an important Tertiary revolution in the northern Andes.

In view of the foregoing facts, it appears that intervals of eruptive activity occurred during the deposition of the Guaduas beds, although more profound subsequent disturbances have left them in highly inclined attitudes and at various elevations, from the level of the valley floor, at 1,000 feet, up to above 9,000 feet on the Plateau. These later disturbances were accompanied by displacements of great magnitude along the west slope of the cordillera. In many places along this zone the coal veins at the base of the Guaduas series have been exposed by faulting, as

[14] H. Stille: Geolog. Studien im Gebiete des Rio Magdalena, pp. 296, et seq.

may be seen along the Rio Negro, Rio Colorado, Rio Sogamoso, and farther north. In the blocks intervening between these longitudinal faults the strata have generally an easterly dip from 20 to 60 degrees, sometimes forming a succession of steps.

According to Hettner,[15] a longitudinal trough of Guaduas beds occurs on the east slope of the East Cordillera at Medina, the north and south extent of which is not known, though similar beds are found far to the north on the east slope of the cordillera.

In the basin of Maracaibo beds said to be the equivalent of the Guaduas in age and character occupy a broad area and are folded into a general syncline, with local structures, anticlinal and other.

Conditions of deposition.—It is believed that during Guaduas (Eocene) time the sea spread over a large part of northern Colombia; that the mountains of the period here had but little elevation above it; that among them inlets extended from the sea, forming long and relatively narrow estuaries; that beyond the limits of even partly marine waters low valleys extended, occuped in part by a long chain of inland lakes, the outward drainage of which entered the embayments of the Magdalena and Maracaibo, building up deltalike deposits in each, which contained but little coarse detrital matter, except local tuffs, though much vegetable debris, especially in the early stages of the period; that the coarser detritus of the time was impounded in the landlocked basins or marine estuaries, which collected also vegetable matter from the inflowing rivers; and, finally, that the shores and land areas surrounding these various basins contained formations from which much iron was derived by denudation and carried into their deposits. These older formations were partly of old crystalline rocks and partly of early Cretaceous sediments, both rich in iron. The belief of Dr. Stille that the Guaduas beds contain gypsum and primary concentrations of salt is hardly in accord with observations by the writer. While both minerals have been observed associated with Guaduas deposits, in all such cases, including those of Zipaquira and Nemocon, they are of secondary origin and arise from the purely marine Cretaceous strata beneath the Guaduas. This was undoubtedly the view of Dr. Scheibe with reference to the salt deposit at Nemocon, where the author spent some days with him in the field.

No molluscan remains of marine, or even partially marine, character have been authentically reported, nor were any such seen by the writer in the Guaduas deposits of the Plateau. These deposits were formed in

[15] A. Hettner: Die Kordiere von Bogotá, 1892, pp. 35 and 38.

or under conditions of fresh water and, as far as known, lack any of the characteristics of marine or partially marine deposits.

Conglomerates are not abundant in this series, even on the Plateau, and clay shales, mudstones, and fine sandy shales predominate. From these facts it may be inferred that the mountains of the present Plateau region were not high, and that an equable climate prevailed. The coal and carbonaceous deposits seem to harmonize with, if they do not corroborate this view, although abundant rainfall seems probable. Possibly the conditions were not very different from those of the present about the mouth of the Orinoco, though the streams were smaller.

That the climate was, furthermore, tropical is evident from the presence in the Guaduas coal-bearing strata at Bogotá, according to E. W. Berry,[16] of the genus *Musa*, which may be assumed to have been, as it is today, characteristic of tropical conditions. Dr. Berry was unable to give the horizon of the beds from which the seeds described by him were obtained; but, as there are no other Tertiary deposits here than Guaduas, the fossils, whatever age they may represent, undoubtedly were derived from this series.

Bituminous character of the Guaduas.—Besides the coal veins which characterize the Guaduas series, there are many evidences of its being a primary source of petroleum. At many places along the west foot of the East Cordillera springs of asphaltic oil issue from these or later beds, and at other places beds of bituminous sand are intercalated in them. Such occurrences are well known both north and south of the lower Sogamoso River and in the upper valley of the Magdalena, as on the Rio Negro, Rio Seco, and at other points farther south. They are found frequently in beds younger than the Guaduas and therefore overlying the latter. Petroleum is now being produced in quantity in the district of the Rio Colorado by the Tropical Oil Company.

While it has not yet been definitely proved that the oil produced in this district is primarily derived from the Guaduas (La Paz) strata, this should be inferred from a study of the sedimentary groups found in this region. Even if it were determined that the oil comes directly from later beds, it may still be held that it originated in the Guaduas series, since no other contains organic materials which have quantitative adequacy as a source. It has been claimed by some that all of the oil in Colombia probably comes from the Villeta group of the Cretaceous.[17] As far as actual developments have gone in petroleum production in Colombia, most of it

[16] E. W. Berry: Am. Journ. Sci., vol. x, 1925, pp. 530-537.
[17] O. Stutzer: Zeit. der Deutsch. Geol. Gesells., Bd. 75, p. 187.

comes from the estuarine or delta areas of the Guaduas near the Magdalena and its tributaries, where it can not be shown that any group of the Cretaceous strata has contributed. The author sees no sound basis for such view, but regards the Guaduas series as the primary source of the petroleum and of all the petroleum that is likely to be produced within the limits of nonmarine Eocene or later deposits in Colombia.

It is held by some authorities that estuarine or delta conditions are favorable, if not necessary, for large accumulations of petroleum, and in fact that petroleum is really formed by alteration of land-derived materials that are brought in by rivers and find lodgment in the sediments of deltas, especially in tropical regions. Vegetable matter in the form of

FIGURE 4.—*Guaduas Sandstone saturated with Asphaltum*

This locality is 8 miles southeast of Honda, in the upper valley of Rio Magdalena. Photograph by K. D. White.

humus, plant debris, or even wood, brought down by rivers have been suggested as the materials from which oil is derived under the physicochemical processes of nature, which include partial and special decomposition.

Without commending this view of the matter, it may be said that the chief essentials proposed by its advocates are undoubtedly present here, just as they are in the basin of Maracaibo, which has been referred to by Cunningham Craig [18] as an example illustrating such an hypothesis. The Magdalena River, the Rios Carare, Opon, Colorado, Sogamoso, and Lebrija all enter the delta area, which includes the only oil district of commercial

[18] C. Craig: Oil finding, etc. London, 1920, pp. 27-43.

value yet proved in Colombia, the areal extent and richness of which is not yet known. The delta conditions belong especially to the Eocene (Guaduas) time, and the coal and carbonaceous beds within its strata not only bear witness to the accumulation of plant remains, but incidentally also of all the various products of vegetable decomposition, partial or other, and the area should therefore supply data comparable to any for illustrating the soundness of this conception.

However, the delta was not entirely free from marine conditions during Guaduas time, as already shown, even farther among the mountains than the proved oil district, and it is possible that marine organisms may have played some part in the genesis of the oil. The inflow of the tides may easily have brought in large quantities of plankton, including Foraminifera, and impounded their remains in favored parts of the delta. Such organisms are abundant in the Eocene in its purely marine facies not far away, where many types of Foraminifera have been found in abundance.

At the outward extremities of the delta, where marine and estuarine conditions mingle and interlock, lateral migration of petroleum fluids could have taken place, and the direction of such migration would have been toward the delta head, where the more porous strata and otherwise suitable conditions were developed for their retention.

Whichever view may be accepted as to the materials of primary source for the petroleum of the delta region of Colombia, whether marine or nonmarine, there is an abundance of both or of either in the Eocene deposits to supply all that could be demanded by theoretical considerations.

As far as known to the writer, all of the occurrences of petroleum and bituminous sands found in the Guaduas, as well as in the marine Eocene, are stratigraphically above the horizon of the coal veins.

Oligocene Series

Concerning the existence of Oligocene rocks in Colombia, little can be said at present, though evidence of their occurrence is claimed by various geologists. In view of the fact that they occur in some volume in Jamaica, Panama, Peru, and in the basin of Maracaibo, they should be expected also in Colombia. Limestones with numerous Foraminifera have been found in the marine provinces, as on the upper tributaries of the Rio Sinú, near Tolu Viejo and near San Andres, Department of Bolivar. Samples from the latter place, taken from beds associated with the "Bombo shales" described by Beck,[19] were submitted to Dr. Vaughan.

[19] E. Beck: Econ. Geol., vol. 16, 1921, p. 465.

who pronounced them to be Oligocene in age.[20] The proved Oligocene of this section does not appear to exceed 400 feet, though overlying strata have been called Oligocene with some doubt.

These shales doubtless represent a part of the Lower Tertiary series of the Carmen-Zambrano section lying between known Eocene and Miocene beds, as described elsewhere,[21] though as yet there has been no definite determination of the exact horizon.

In the Canal Zone, according to MacDonald,[22] the Oligocene has a thickness of somewhat over 1,000 feet, consisting of conglomerates, tuffs, sandstones, lavas, limestones, etcetera, lithologically various in character.

Arnold states that in the basin of Maracaibo, as well as in Colombia, Oligocene strata may be the source of some of the oil, though he gives no evidence as to their age. According to Garner,[23] strata of this age are found in western Venezuela, concerning which he says:

"In western Zulia the Oligocene is made up of dark-brown carbonaceous shale, sandy shale, and thin-bedded sandstones, about 2,000 feet in thickness." . . .

In a later note[24] he includes the Rio de Oro and Las Melones formations in western Venezuela in the Oligocene, but with some reserve.

Such evidence of Oligocene rocks as are known in Colombia are found only in the marine provinces of the Tertiary. In the nonmarine areas no such evidence has been found, though their existence can not be positively denied.* Here, as in the basin of Maracaibo, Oligocene strata do not enter the mountain districts to the west in the same volume in which they occur in the lower coastal areas farther east.

The marked unconformity between the Guaduas (Eocene) and the Barzalosa (Miocene) in the upper valley of the Magdalena may be regarded as an evidence of an hiatus in deposition during Oligocene time. In the estuarine areas of the Tertiary, in the central valley of the Magdalena, it is possible that a portion of the La Paz series may be Oligocene, but such an assumption is as yet unsupported by any known evidence. For the present, therefore, belief in the existence of any nonmarine Oligocene deposits in Colombia must be withheld, at least until definite evidence of such has been discovered.

[20] H. S. Gale: Trans. Am. Inst. Min. and Eng., vol. 68, p. 1026.
[21] F. M. Anderson: Bull. Am. Assn. Petr. Geol., vol. 10, 1926, p. 398.
[22] MacDonald: Bull. 103, U. S. Nat. Mus., 1919, pp. 526-542.
[23] A. H. Garner: Trans. Am. Inst. Min. Eng., vol. 71, 1925, p. 1364.
[24] A. H. Garner: Petrol. Develop. and Technol. in 1925. Am. Inst. Min. and Met. Eng., 1926, pp. 678-681.

* See footnote under Eocene, p. 604.

Miocene Series

General statement

Like the Eocene series in Colombia, the Miocene shows two or more distinct facies and provinces, corresponding to those of the Eocene in character and position, in large part at least. Both marine and nonmarine deposits abound and probably also some of estuarine character, the definite proof of which has not yet been found.

Marine facies

Along the Caribbean coast and also forming a narrow zone along the Pacific, or extending from the Isthmus of Panama eastward as well as southward, the marine Miocene series has wide distribution. In both directions it extends along the seaboard at intervals as far as the limits of Colombia. In general, though not in detail, the marine Miocene is concentric with the Eocene deposits. Along the north coast they extend from Gatun, Panama, to the mouth of the Magdalena and appear farther east at Rio Hacha. Inland they stretch along the lower valley of the Magdalena at least as far as El Banco, and to a considerable extent, not yet fully known, into the valleys of the Rio Sinú, Rio San Jorge, and the Rio Cesar. In the Sinú Valley they occur above Monteria and about San Andres, extending from here eastward into the valley of the San Jorge.

Along the north coast the marine Miocene is well represented by the Tuberá-Usiacuri series, consisting of clay shales, sandy shales, and sandstones, each in thick groups, aggregating on the whole not less than 3,500 feet of strata. The lower group contains numerous species of Foraminifera, while the sandstones at the top contain an abundance of marine mollusks composing a fauna similar to that of Gatun.

Nonmarine facies

Distribution.—All the distinct facies of deposition recognizable in the Eocene deposits of Colombia probably continue into the Miocene also. Of the purely nonmarine deposits there can be little question, and it is believed that a careful analysis of the known facts will make it evident that at least a large part of the estuarine areas of the Eocene remained under similar conditions throughout the Miocene. In the upper valley of the Magdalena deposits believed to be Miocene extend over a large part of the valley in great thickness. From Honda they extend southward to above Natagaima, and they occupy both borders, outcropping on both sides of the valley at Tocaima and Gualanday, and even farther west on the Mesa of Pica Leña. At Honda and eastward to the Rio Seco these beds

are well exposed, where along the road to Guaduas they form a series 3,000 feet or more in thickness. They are still better exposed a mile south of Tocaima, along the Rio Bogotá, and also along the Rio Coello between Chicoral and Gualanday, and on the Mesa of Pica Leña, where they occur at an elevation of 3,500 feet. In these areas they have been specially studied by Dr. R. Scheibe, who clearly shows their unconformity with the Guaduas series and who has given them the name of "Barzalosa series." [25]

In the central valley of the Magdalena, between El Banco and the mouth of the Rio Nare, it is probable that estuarine conditions similar to those of the Eocene continued in the Miocene. While brackish water faunas have not been found in the Oponcito (Miocene) deposits of this area, these deposits were not free from marine influence. Molluscan shells found at Las Infantas showed the form and surface ornamentation of *Cerithium* and other marine forms capable of living in partly fresh water. Fragments of species resembling *Natica* have also been found in this district, which shows the influence of ocean water, notwithstanding the fact that the Miocene rivers brought into its area vast volumes of fresh water; but, if there were no direct evidences of marine influence here during the Miocene, it might be inferred indirectly from environmental facts. The area of the Oponcito deposits coincides with the central valley of the Magdalena and extends from the mouth of the Rio Nare to El Banco, a distance of some 200 miles, and has a width of about 50 miles. The present surface elevation of this area ranges from 150 feet at El Banco to 600 or 700 feet about its borders, while marine Miocene deposits outside of it are found at elevations of 800 feet, from which facts it is presumable that the entire delta area was flooded by the sea and subsequently lifted from it. On the other hand, the thickness of the Oponcito series has been computed at over 7,000 feet of well stratified, though sometimes cross-bedded, formations, showing the characteristics of shallow water, deltalike deposits.

According to the brief description given by Garner of the Miocene deposits of the western border of the Maracaibo basin, they are comparable to those of the Oponcito series. Concerning these deposits he says:[26]

"There are few fossiliferous horizons in the Miocene of Zulia. In both western and eastern Zulia the Miocene is made up of a series of alternating beds of clays and sandstones with a thickness of 5,000 to 8,000 feet. The clays are soft and mottled white to red. The sandstones are massive, friable, poorly sorted, coarse and lenticular."

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[25] R. Scheibe: Mem. del Minist. de Obras Publ., etc., 1918, pp. 170-173.
[26] A. H. Garner: Trans. Am. Inst. Min. and Met. Eng., vol. 71, 1925, p. 1365.

In the Plateau region of Colombia no Miocene accumulations, either marine, lacustrine, or landlaid, have been recognized with certainty. The alleged marine Miocene formations described by Gutierrez [27] have not been identified by any other writer, and although they have been searched for by geologists, their conclusions have been negative.

A Miocene or younger plant-bearing formation near Leiva has been referred to by E. W. Berry,[28] concerning which the following notes are offered: Leiva is situated on a tributary of the Rio Moniquirá, in Boyacá, at an altitude of 7,300 feet, and in a basin that appears to be the terminus of a trough of Guaduas beds extending northerly from Nemocon and the Lake of Suesca, and which is surrounded by higher ridges of Cretaceous marls, slates, etcetera, according to an account of the locality by Manuel Ancízar. Concerning the deposits found here he says in part:

"At the foot of the hills, and in very irregular curves, there extends a little plain formed of the sediments of a lake which might measure more than five leagues in length and two in greatest width, and (which) had been drained near the place where the copper mines are today," etcetera.

In a later paragraph he describes veins of coal occurring in these beds, which coals in character seem to resemble that of the Guaduas in other places. Various springs occur near the town of Leiva, some of which have formed deposits, concerning which Ancízar relates:

"Near Leiva and on the road to Tunja, arise three thermal springs, one of them warm and ferruginous, which breaks out around a small promontory of sediment and forms natural baths, not yet utilized," etcetera. . . .

From the surroundings it might be inferred that some of these springs would deposit calcareous travertine. Some of the plant remains found at Leiva are said to occur in travertine, though in what relation to the lake deposits is not known. It is of course possible that these lake beds are of Miocene age, or that the travertine deposits are Miocene, though later in age than the lake beds. The value of plant remains preserved in travertine for age determination is doubtful.

The absence of Miocene strata, marine or terrestrial, from the Plateau region of Colombia might be attributed to some elevation and denudation in the mountain areas of Colombia during this period. The post-Eocene (Oligocene) elevation of the mountain regions began prior to the Miocene, but continued into and through it, except in the area of the *graben-sink* of the Magdalena, which was faulted down at the close of the Oligocene.

[27] S. A. Gutierrez: Anales de Ingenieria, Bogota, vol. xx, 1913, pp. 323-324.
[28] E. W. Berry: Bull. Geol. Soc. Am., vol. 35, p. 782.

Character of the deposits.—The lithologic composition of the Barzalosa deposits is interesting and important from the viewpoint of geologic history, particularly in its scarcity of volcanic materials. In the main the deposits are coarsely detrital, especially in the upper valley of the Magdalena. In this area sandstones and conglomerates predominate, the former being in part fine grained and the latter sometimes very coarse grained, often containing pebbles and small boulders. The materials of these boulders are various, being for the most part metamorphic rocks such as are common in the Central Cordillera, including quartz, quartzite, black or dark-colored cherts, crystalline, gneissic or granitoid rocks, and occasionally pebbles showing the lamination and pitted surface of the Planer-like shales of the Guadalupe group of the Cretaceous, abundant in the East Cordillera. Near Gualanday the texture of these beds is in part very coarse, the pebbles being more abundant and larger than in most other localities. The conglomerates here are sandy and of a mottled color, interstratified with red sandy clays, the color of which dominates the group, staining the soil and the water flowing from the formations after a storm.

On the opposite side of the valley south of Tocaima the Barzalosa beds are for the most part sandy, with but few beds of conglomerate exposed, although the base was not seen. According to Scheibe,[29] the lower group

> "consists of mottley clays in which are intercalated some (usually three) distinct beds of conglomerate a meter in thickness and separated by some meters of clay. The pebbles of the conglomerates are almost exclusively rolled fragments of planers from the Guadalupe group; besides, there are beds of white sandstone." . . .

In general the beds on the west border of the valley are coarser and more characteristic, lithologically, of the Central Cordillera. While a few of the pebbles are of andesitic rock, they are not abundant, except farther south in the Magdalena Valley and on the flanks of the Central Cordillera, from which they probably came. Stille was convinced,[30] however, from his study of these beds that volcanic materials were abundant, recurring in them at certain intervals as distinct phases. Near the bottom of the series between Natagaima and Dolores he describes a horizon containing pebbles of labradorite porphyrite (page 310).

On the opposite side of the valley above Gualanday the texture of the beds in the lower part of the series is finer than it is higher up. Fine-grained ashy sandstone and sandy shale are exposed in some of the rail-

[29] R. Scheibe: Mem. de Obras Publ., 1918, p. 170.

[30] H. Stille: Geolog. Studien im Gebiete des Rio Magdalena, etc. Festschr. von Koenen, pp. 305-315. Stutgart, 1907.

FIGURE 5.—*Type locality of Barzalosa beds near Tocaima*

The view is taken looking southeast; Guadalupe (Cretaceous) mountains in the background; valley of Rio Bogotá on the left.

FIGURE 6.—*View of Gualanday on the Rio Coello*

Eastward dipping Barzalosa beds on the left; east border of the plain of Pica Leña on the right, composed of Honda beds covered by alluvial terrace gravels.

road cuts, which include carbonaceous layers with determinable plant remains. The lower beds of the series are covered by more recent gravels, but as far as exposed here the series contains the following groups, given in ascending order:

1. Fine-grained, ashy sandstone and sandy shale with carbonaceous layers (basal beds not found), 800 feet thick.
2. Coarse sandstone and conglomerate of brick-red color, with a few pebbles of andesitic rock, 700 feet thick.
3. Gravelly sandstone with pebbles of siliceous rock, cherts, white quartz, schists, crystalline rocks, etcètera; thickness not known.

The Barzalosa beds of this district attain a total thickness of not less than 3,500 feet, as seen between Chicoral and Gualanday, along the Rio Coello, and extend northward for an unknown distance.

In the district of the delta valley, as also at Honda and Tocaima, pebbles of chert from the siliceous shales of the Guadalupe group, showing molds of characteristic Foraminifera, are often found in the Barzalosa beds, although on this side of the valley they are negligible in quantity as compared with their abundance in the following series, described later.

In the Honda district the character of the Barzalosa series is partly shown in the photographic view (page 618), looking eastward across the river from Honda. The formations shown in the ridge crossing the stream just above the village is a part of this series. The beds extend from here eastward nearly to the Rio Seco, with an easterly dip of 25 to 35 degrees, though Hettner's estimate is greater. Its aggregate thickness is not less than 3,000 feet and it may be more. The beds consist of pebbly sandstone of a yellowish gray color, with local layers of conglomerate. The strike of these beds varies from north-south to north 25 degrees east, with dips to the east or southeast. Farther south and on the west side of the river, near Mendez, the strike swings to a different direction and the dip is to the southwest at an angle near 30 degrees. It was here that Hettner noted a dip toward the west in strata that he classed with his Honda beds.

A prolonged search in the Barzalosa series east of Honda failed to disclose it in more than a few pebbles of volcanic rock and none such as are abundant in the younger series west of the river. The topographic aspects of the two series is well shown in the illustrations here introduced, as a little study will prove.

Literature.—Karsten [31] first attempted a general description of the Tertiary formations found in the upper valley of the Magdalena, in the

FIGURE 6.—*View of Gualanday on the Rio Coello*
Eastward dipping Barzalosa beds on the left; east border of the plain of Pica Leña on the right, composed of Honda beds covered by alluvial terrace gravels.

[31] H. Karsten: Geologie de L'Ancien. Colombia, etc. Berlin, 1886, p. 28.

FIGURE 7.—*Eastward dipping Barzalosa Beds at Honda, Rio Magdalena*
The ridge in the right foreground is formed of horizontal Honda beds.

Cauca Valley, and in the valley of the Patia and at other places, though without assigning them to any more definite period than the Tertiary, referring them to a "Tertiary complex," which seems to have included the Guaduas as well as later series. Little can be made of his descriptions, although he probably suspected that the beds most conspicuous along the river at Honda belonged to a series later in age than the Guaduas, found farther east and at higher altitudes. However, he gives some information as to the general distribution of the Tertiary formations about interior of the country and on the Plateau. As a pioneer and an unprofessional geologist, his descriptions are often surprisingly good.

Hettner[32] next undertook a discussion of these nonmarine Tertiary beds in the upper valley, and under the name "Honda beds" included a great thickness of strata to the east of Honda which clearly lie beneath those first covered by his description, as will be shown later. It is not even clear that Hettner did not also include in his Honda beds some strata that belong to the Guaduas, particularly in the vicinity of Bogotá.

Dr. Hans Stille,[33] in discuss-

[32] A. Hettner: Die Kordillere v. Bogotá, 1892, loc. cit.
[33] H. Stille: Geolog. Studien im Gebiete des Rio Magdalena, 1907.

ing the Tertiary formations of this region, endeavored to follow Hettner as far as possible and was led into some of his errors in this confusion of series. He says in part:

"With Karsten and Hettner, I assign to the Tertiary a very thick complex of formations, sometimes very coarse-grained, at others equally fine-grained, which resulted from the breaking up of the older rocks of the cordilleras and usually overlie them unconformably."

That Stille had no clearer insight into the stratigraphic relations of the several Tertiary series is readily seen from the text which follows the above quotation. He believed that the horizontal beds west of Honda curved downward at the river and passed beneath those to the eastward, and so drew the profile representing his view of the relations. Like Hettner, he seems to include in the Honda beds strata that properly belong to the Guaduas series, as well as the Barzalosa. This profile (Stille's figure 2, plate 10) is in other respects so excellent and expressive that it is here reproduced with only such modifications as seem necessary; the only essential change being the introduction of the fault traversing the river at Honda, across which the horizontal series of younger strata normally rest, cut only by river erosion. These are the proper *Honda beds*, as will be explained later.

The beds lying to the east of Honda are the northward continuation of the Barzalosa-Gualanday series described by Scheibe,[34] to whom is due the credit of supplying the key for the proper segregation of the several Tertiary series. He has shown that the Barzalosa series lies unconformably upon the Guaduas and below the Honda series, as restricted in the following pages.

Washburn and White [35] have more recently drawn a stratigraphic column for the Honda district, in which the "Honda formation" is described in the following language:

"Formation, 8,000 feet thick, composed of thick members of sandstone and conglomerate, with a subordinate amount of clay and sandy shale. Color is gray to greenish; sand grains and pebbles are mostly of quartz and black chert, but with some igneous material. Formation well exposed in Cordillera de Honda. Strata folded."

With the exception of the great thickness of strata mentioned in this text, the formation is evidently that properly included in the Barzalosa series of Dr. Scheibe. The name *Honda* beds, or series, must be reserved

[34] R. Scheibe: Loc. cit.
[35] C. W. Washburn and K. D. White: Trans. Am. Inst. Min. and Met. Eng., vol. 68, 1923, p. 1026.

for that portion to which Hettner first applied it, as hereafter shown. The "La Mesa Formation" of their column seems to represent this series.

Dr. Otto Stutzer,[36] in reviewing the Tertiary formations of the Magdalena Valley, has proposed a classification somewhat different from that employed in this paper, though the basis of his views is not at all clear and in part it must be considered as questionable. However, among other valuable suggestions, he places the Honda bends (Scheibe) as discordantly overlying the Gualanday and Barzalosa beds (Scheibe) and says in part:

> "Honda beds and Gualanday beds are distinguished thus, that many strata of Honda beds contain andesitic material, while they fail to occur in the Gualanday beds."

His correlation of the Honda beds with the Oponcito beds properly refers only to the "Upper Oponcito" and not the main body of the formation here classed as Miocene, and which appears to be covered unconformably with the so-called "Upper Oponcito."

Age determination.—The Barzalosa series has been shown by Dr. Scheibe to be unconformable on the Guaduas near Tocaima, and as they rest on rocks older than the Guaduas west of Gualanday and southward, about Ortega and Chaparral, we may accept this unconformity as a general relation; and as Oligocene strata have not yet been proved outside of the purely marine provinces of the Colombian Tertiary, it might be assumed that this unconformity and the hiatus represented by it corresponds to the epoch of the Oligocene. Such an assumption, however, would permit the assignment of the Barzalosa series to the Miocene—a correlation which, in view of their volume, lithologic character, and resemblance to the marine Miocene about the north coast, seems to be most natural and best in accord with the known facts. In these purely nonmarine beds, which are referable to the Miocene on stratigraphic grounds, no determinative molluscan fauna has been found, but at widely separated localities fossil plants have been collected which E. W. Berry[37] has determined as Miocene, partly from descriptions of their floras by Englehardt.[38] One of these localities is near Santa Ana, a village about 10 kilometers southwest of Mariquita, on the flanks of the Central Cordillera, at an altitude of about 3,260 feet above sealevel, or 2,600 feet above the river at Honda. According to Walter Bergt,[39] who did the petrographic work on the col-

[36] O. Stutzer: Beitr. zur Geol. und Min. von Kolombian (Sudamer). Neues Jahrb. f. Min., Geol., etc., Beil. Bd. 52, pp. 162-174.

[37] E. W. Berry: Bull. Geol. Soc. Am., vol. 35, 1924, p. 782.

[38] H. Englehardt: Abh. Senck. Naturf Gesells., Bd. 19, 1885, etc.

[39] W. Bergt: Geol. Studien in der Rep. Colomb., p. 38, Berlin, 1899.

lections of A. Stubel, these plants were found in andesitic tuff, which he determined to be such only by the aid of the microscope. Concerning this material he says:

"Plant-bearing andesitic tuff (pumicestone?) of Santa Ana.—Tolerably firm, very uniformly, and usually fine-grained, grayish white; loses color a little by strong pressure; adheres feebly to the tongue; fuses before the blowpipe to a gray flux. Under the microscope one can not immediately perceive the andesitic origin of the material, probably on account of its fineness and the admixture of clayey substance."

Fossil plants of this age have also been described by Englehardt from near Buga, in the Cauca Valley, where they are said to occur also in volcanic ash or tuff, at about the same elevation above the sea, and according to E. W. Berry a Miocene flora has been found at Leiva, and at other places, though he gives no description of the strata in which they have been found at any of these places. The locality at Leiva has already been referred to.

The definite connection of the plant-bearing beds at Santa Ana with the Barzalosa beds found in other parts of the upper valley has not yet been made directly, although the assumption that the Santa Ana beds represent a low horizon in the Barzalosa series seems to be well supported indirectly. The area at Santa Ana is severed from that east of Honda by faulting, as shown in the revised

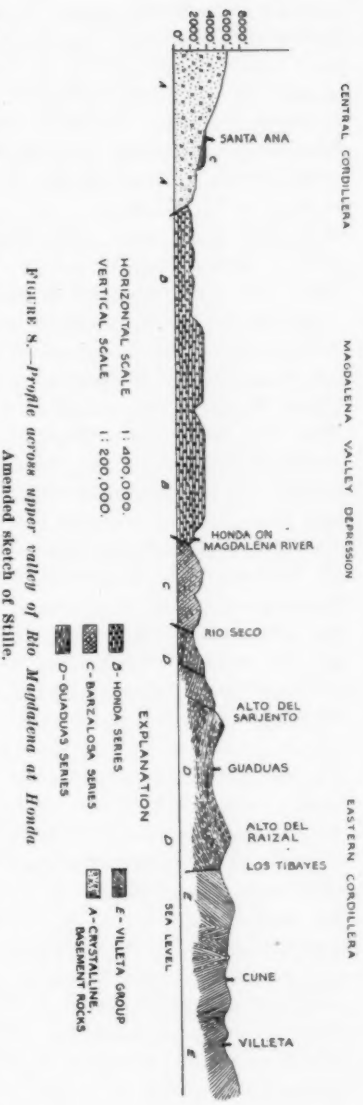

FIGURE 8.—*Profile across upper valley of Rio Magdalena at Honda*
Amended sketch of Stille.

section here given, while on the west side of the valley it is not far removed from the northward continuation of the Barzalosa beds lying northwest of Gualanday and having about the same elevation above the sea. The areal continuity of the beds has not been shown, though it may be only from lack of investigation.

On the Plateau no undoubted Miocene deposits have been found, and it is more probable that this region is especially marked by their absence.

On the whole, with reference to the Barzalosa (Oponcito) series, the best basis of classification or correlation is found in its stratigraphic relations, or by noting its position in the sequence of nonmarine and partially marine deposits compared with the Miocene in the sequence of marine deposits, as already suggested. Such a basis, of course, contains an element of assumption, but it is believed to be sound.

Structures of the Miocene.—The structural features of the Miocene series, like those of the Eocene, are various in different districts. In the highly folded districts of the marine Tertiary the Miocene strata within their areal limits are usually involved with the older Tertiary in their complicated structures, and the same is true in their nonmarine areas and also in the areas where delta conditions were shown for the earlier Tertiary deposits, namely, on the lower Sogamoso and Colorado rivers.

In the folded and faulted zone along the west slopes of the East Cordillera, wherever Miocene rocks occur they have suffered folding and faulting, though not to the same degree as the older series. The Barzalosa beds at Honda have a strong easterly dip of 20 to 30 degrees, with a variable north to south strike. These easterly dipping beds occupy a block having a width of 4 or 5 kilometers, between the Magdalena and the Rio Seco, while the exposed thickness of the series is not less than 3,000 feet. The westward-facing escarpment opposite Honda evidently had its origin in a line of faulting having a course of north 20 to 30 degrees east, crossing the river here at a sharp angle. A similar fault-line traverses the Rio Seco, the two inclosing the block of the Barzalosa series.

In the district south of Tocaima the Barzalosa beds have a strong dip of 20 to 25 degrees to the south and southwest. They doubtless underlie the entire basin to the south, in which, in addition to having a general synclinal structure, they are also crossed by faults along their eastern border between the Rio Bogotá and the Rio Fusagasugá.

On the western border of the Magdalena Valley the structural conditions are well shown between Chicoral and Gualanday, where they are crossed by the Rio Coello. Near Chicoral, on the north side of the river, the beds have a north to south strike and a dip of 40 degrees to the west. They form a steep escarpment facing eastward, undoubtedly produced by

faulting, although Cretaceous beds lie along the east margin of the fault-line. Farther west, at Gualanday, the structure of the Barzalosa beds is reversed, the strike turning to the northeast and the dip to the southeast at an angle of 40 degrees. Between Gualanday and Chicoral the beds are folded into an anticline of considerable extent, having a northeast to southwest strike. Thus it appears that between the Cretaceous area near Chicoral and possibly similar formations west of Gualanday the Barzalosa series has been pressed into a number of longitudinal folds, anticlinal and synclinal alternating. Near Gualanday, as at Chicoral, faulting has left these strata highly inclined and uplifted, with escarpments facing outwardly toward the west.

In the district of the lower Sogamoso and Colorado rivers the entire Tertiary series, including the Miocene (Oponcito), is folded into a succession of anticlines and synclines having a general strike of north 20 to 25 degrees east. The exact number of these folds is not known, although two or more anticlines are crossed on the old road from Barrancabermeja to San Vicente, and others are reported farther south. According to the report of C. O. Stillman, quoted by Degolyer,[40] not less than four such structures are known and partly proved by drilling, while other reports place the number at seven or more. The Infantas anticline is a sharp and in part overturned fold which apparently brings the Guaduas beds to the surface north of the Colorado River. Whether any of the faults described before as crossing the eastern border of the district actually cut the Miocene beds is not definitely known, though presumably they do so.

Conditions of deposition.—From a careful consideration of the evidence obtainable, it is apparent that the physiographic conditions of earlier Tertiary time continued during the Miocene, although considerably altered. The drainage lines of the Eocene were inherited by the Miocene, though doubtless with some changes. The earth movements, dislocations, foldings, etcetera, begun or active at the close of the Eocene, produced at the epoch immediately preceding the Barzalosa the semblance of a *graben* depression which later became greatly accentuated following the Miocene. During this period, however, the activity of the streams was increased, as will be shown later.

From the highly folded and faulted condition of the Miocene strata in both marine and nonmarine provinces, it is evident that earth movements and uplift followed the Miocene or, in fact, brought the period to a close. That these disturbances were greater in degree than those immediately preceding the Barzalosa (Miocene) period seems to be proved by the fact

[40] E. Degolyer: Petrol. Develop. and Techn. in 1925. Am. Inst. Min. and Met. Eng., N. Y., 1926, p. 544.

that the angle of inclination of the latter strata is usually much greater than the differential angle between them and the earlier beds.

While the *graben* within which the Barzalosa-Oponcito series is confined had its origin in post-Guaduas (pre-Barzalosa) time, it is not necessary to believe that great differential relief resulted at that epoch. Movements of dislocation and uplift followed the deposition of the Barzalosa, which greatly augmented this relief in the environs of the *graben* and added to the previous inclination of the Guaduas strata that acquired by the Barzalosa beds in this area. The structures of the earlier beds is thus cumulative, being the result of continued additions.

Evidences of petroleum.—While in general the rocks of the Miocene series, as here defined, are detrital and for the most part coarsely textured, there are some reasons to expect petroleum to be found in them at some places, where favorable conditions of structure and strata exist. In the marine provinces of the Miocene, at least, evidences of oil are frequent, occurring as springs of tarlike oil, bituminous sands, gas springs, "mud volcanoes," etcetera. In the nonmarine areas they are less frequent, but nevertheless furnish some promise of commercial deposits. In the district of the Colorado River some of the asphalt deposits and bituminous sands are said to be associated with the Oponcito series, which view seems probable. Structures undoubtedly favorable for the accumulation of oil are found here in this series, as they are also in the upper valley of the Magdalena, and secondary, if not primary, deposits of oil may well occur in them, since they are underlaid by Cretaceous and later formations in which petroleum could have originated. At the present, however, no direct evidence that the Miocene strata, marine or nonmarine, are capable of commercial productions of oil are known to the writer.

Pliocene Series

General statement

The Pliocene deposits of Colombia are of more than ordinary interest on account of the light they throw on the age and history of the Andean mountain system. Such deposits are widely scattered over the continental borders, in both marine and nonmarine environments.

Marine facies

Marine Pliocene deposits are well known everywhere about the Caribbean region and have been described from widely separated stations on the mainland and islands surrounding it. Among such deposits are those described by MacDonald[41] as found on the west shore of Limon Bay,

[41] D. F. MacDonald: Bull. 103, U. S. Nat. Mus., 1919, pp. 532-544.

Panama, consisting largely of "bedded coquina," etcetera, in which there are great numbers of barnacle and other shell fragments and a few determinable fossils. Deposits doubtless contemporaneous with these are found at intervals along the Colombian coast east of the Gulf of Uraba. For the most part they are sandy or marly beds capped with coralline limestone, forming a series which rests discordantly on the Miocene. This series, about 1,000 feet in thickness, capped by coral limestone, occurs near Puerto Colombia and Salgar and southward to Barranquilla and Galapa. Such limestone deposits are found at the summit of Cerro de La Popa, near Cartagena, Punta Pua, some miles to the east, and at Turbaco. At most of these places the beds are elevated from 100 to 500 feet above the sea and are inclined from 5 to 15 degrees from the horizontal. Their correlation with the Pliocene of Limon Bay is based largely on stratigraphic relations, though the beds are quite fossiliferous at many places. The walls and some buildings of Cartagena are built of this coral rock. A quarry in the outskirts of Barranquilla exposes coral limestone containing many fossils of late Tertiary age.

Along most of the larger rivers, as the Magdalena and its tributaries, well stratified deposits are to be seen, which seem to be continuous with those near the coast. In the district of Barrancabermeja such deposits, forming a group 800 to 1,000 feet in thickness, covers the Oponcito series over a wide area. Similar deposits have been observed at Puerto Berio and southward toward the Rio Nare and have been described by Stutzer as equivalents of the Honda series.

NONMARINE FACIES

Views of other investigators.—The Honda beds were first described by Hettner[42] in his discussion of the geology of the East Cordillera. Hettner, however, did not clearly define the series and in fact did not distinguish the several Tertiary groups now known to occupy the region over which he believed his Honda beds to extend. In his earliest description of these beds he says:

> "On both banks of the Magdalena River above Honda, and also at certain places embraced deeper in the mountains, is found a greenish gray tufaceous sandstone, which seems to have been derived from the disintegration of volcanic rocks in the central cordillera." . . .

This statement clearly refers to the deposits lying immediately west of Honda and forming the scattered ridges between this village and Mariquita and extending from here southward along the west side of the valley

[42] A. Hettner: Die Kordillere von Bogotá, etc. Peterm. Mittell., Suppl. No. 104, Gotha, 1892.

as far as Coello or beyond. But unfortunately he continues the discussion of the subject as follows:

"Between Tocaima and Giradot there lies upon the above mentioned system (Guaduas?) variegated clays and sandstones; at Bogotá there is included with it, however, a similar sandstone in a recumbent fold. Fossils are absent, or at least have not thus far been found. If the opinion expressed concerning the composition of this Honda sandstone is correct, it should be Tertiary. It is, however, the youngest of the folded formations." . . .

It would appear from this language that Hettner included one or more series of strata older than that to which he first applied the name of

FIGURE 9.—*Horizontal Honda Beds*

These beds are at the west border of Honda. The Rio Guali is in the foreground; upper valley of the Rio Magdalena.

"Honda beds." In the appendix to the same paper (page 29) he enlarges on his original description of the *Honda beds* thus:

"At and below Honda the Magdalena River forms the west boundary of the Cordillera de Bogotá, where west of the river is found a 20-30-kilometer-wide zone with horizontal tuffs. Immediately over Honda occurs the farthest ridge lying upon the left bank of the river, which it seems to follow as far as Coello. It rises only a few hundred meters, and consists of gray and green tufaceous sandstone and conglomerate, the Honda beds, which strike north and south and dip easterly at about 45°; only at Mendez may be noticed a westerly dip of this ridge." . . .

The formation described in the first part of this quotation very clearly defines and constitutes Hettner's *Honda beds,* and the name is so em-

ployed in this paper. The beds later referred to lie east of the river, where only a dip of 45 degrees can be found, and belong to an older series, the Barzalosa, as stated on a former page. Accompanying photographs illustrate the two series. At the mouth of the Rio Guali are seen the horizontal beds of sandy tuff on the west border of Honda, representing the Honda series, but no such beds are found inclined 45 degrees to the eastward. The series is found at certain points east of Honda resting horizontally across the tilted edges of the Barzalosa beds.

Honda deposits cover almost the whole area of the upper valley of the Magdalena as far south as Natagaima, though they are not confined to the

FIGURE 10.—*Honda Beds with volcanic Blocks weathered out on the Surface*
This locality is 5 miles north of Guataqui, upper valley of the Rio Magdalena. Photograph by K. D. White.

limits of the upper valley. Wherever these beds are found resting upon the Barzalosa their unconformable relation is evident. Scheibe clearly describes this relation in the latitude of Ibagué and Giradot.[43]

The character of the Honda deposits in the upper valley is suggested in the above quotations from Hettner. The entire series seems to be composed of beds of volcanic tuff and ash, with layers of river gravels interspersed. The pebbles are water-worn and rounded and consist of quartz, quartzite, chert, and other metamorphic and plutonic rocks, such as occur in the Central Cordillera. The pebbles of volcanic rock are also rounded,

[43] R. Scheibe: Doc. de la Com. Cient. Nac., 1922, No. 2, p. 7.

as are the others, showing their transportation by the streams of the period.

Beds of volcanic tuff, consisting of pebbles, sand, and ash, make up the larger part of the Honda series and characterize it in all parts of the upper valley. They serve also to distinguish it from the preceding series, the Barzalosa, which, except near its base, has few pebbles or other material of volcanic nature. In the Honda series such material is more abundant at the top and bottom of the section. The highest bed found near Honda is 40 feet in thickness and caps the summit of the hill a mile west of the village. It is almost entirely composed of andesitic tuff, containing rounded and water-worn pebbles of andesite, sand and ash. According to Bergt,[44] this rock should be classed as amphibole-pyroxene andesite. It is light gray in color, having an almost white groundmass, through which are sprinkled many fresh, unaltered crystals of dark pyroxene and hornblende. The materials are all fairly well stratified, though sometimes cross-bedded in their finer condition of sand and ash. Their transportation by water is evident, not alone from their stratification, but from the worn and rounded form of the pebbles, as well as by the intercalated layers of non-volcanic rocks at frequent intervals throughout the series. In thickness it can not be less than 600 feet and when deposited must have been much thicker, since it shows much dissection and reduction by recent denudation.

In the central valley of the Magdalena there are many exposures of stratified clays, sands, and gravels that appear to represent the Honda series. On both sides of the river below Puerto Berrio high banks of sand and gravel extend for many miles, some of which form ridges and isolated hills rising above the level of the river valley. Some of these hills resemble remnants of an ancient elevated delta deposit, now greatly denuded, partly by river action. Examples of this formation are to be seen at and near the village of Berrio, and, according to Stutzer, occupy much of the valley west of the river between this point and the mouth of the Rio Nare. Near the village of Malena, west of Berrio, a series of sands and gravels, 700 to 800 feet in thickness, covers the older basement rocks of the Central Cordillera and have an inclination of 5 to 10 degrees toward the east. In composition it is similar to that along the river. It rises on the hills to altitudes of 1,000 to 1,200 feet, though not in great thickness.

Farther north and on the opposite side of the river, between Barrancabermeja and Las Infantas, similar beds are found, which form the so-called "Upper Oponcito" group, 700 to 800 feet in thickness, covering the

[44] W. Bergt: Geol. Studien in der Repub. Colomb. II, Petrog., etc. Berlin, 1889, p. 34.

Oponcito series, perhaps unconformably. Near the foot of the Ocaña range, east of Loma de Corredor, similar sandstones are found cross-cut by the streams coming from this range. The sandstones are micaeous and contain numerous pebbles of granitic and gneissic rocks. Even as far north as El Banco beds of the same character may be observed.

Whether beds contemporaneous with the Honda extend on the Plateau has not yet been clearly determined. No volcanic deposits have been noticed in the East Cordillera, except perhaps, on its western slopes, though Stille seems to refer to such "at the foot of Honda Street in Bogotá."

While in the upper valley of the Magdalena the Pliocene deposits are in part landlaid, representing coarse alluvial deposits and in part deposits formed in shallow water, in which much volcanic material was entrapped, those of the central valley are of finer grain, well stratified, though often cross-bedded, and are of aqueous deposition, but on the whole of quite similar materials. Near Berrio and, according to Stutzer, southward from this place ashy beds are often found in the series.

On the Plateau, especially in favored places, alluvial deposits are found which may be contemporaneous with a part of the Honda, but their identity remains to be proved. Naturally most of the alluvial deposits found on the Plateau and about the East Cordillera belong to a later epoch and will be considered later.

Conditions of deposition.—Whether or not the upper valley of the Magdalena held an intermontane lake during Honda time or was then, as now, a well-drained valley floor on which alluvial deposits only accumulated is not certainly known. It is difficult to explain how good-sized pebbles and even boulders could have found their way many miles from shore to the central parts of a lake of deep and quiet water, and in view of the regular stratification of these beds and the fact that the river now flows through a narrow defile for many miles below Honda, it can not be said that the valley above was entirely free from lacustrine conditions prior to the development of this gorge, which is of late origin. Fossil wood is often found in the Honda deposits—a fact, however, that has easy explanation in either case.

Probably neither conclusion should be exclusively adopted, and all the facts might be adjusted to the view that shallow-water lakes, or cienegas, existed in this area, which were alternately developed and destroyed by the action of lateral streams. The rapid loading of the valley floor with detritus during an epoch of volcanic eruption to a depth of 1,000 feet or more would probably cause sagging with reference to the outlet. Such

FIGURE 11.—*Honda Beds*

This locality is 3 miles west of Mendez. The view is taken looking west; upper valley of the Rio Magdalena. Photograph by K. D. White.

impounding of debris in the upper valley would continue until volcanic activity ceased to such an extent that erosion of the outlet could again restore the former drainage conditions, the terminal results of which are to be seen in the present denuded and dissected formations constituting the scattered ridges of Honda strata in this region. Probably somewhat analogous deposition took place in the central valley of the Magdalena, with the difference that only aqueous deposition occurred here, with the resultant sagging, subsequent erosion of the outlet, and partial drainage denudation of the deposits.

The general synclinal structure of the Honda deposits appear to bear out this view of the conditions of deposition in both areas of the *graben*. Along the river and in the central parts of the upper valley these beds are usually horizontal, although in a few places where older rocks arise in the valley floor they affect the structure of the

Honda beds accordingly, causing dips at various angles, although in the main the structure is synclinal throughout, except where disturbed by faulting, which is rare.

The history of the Honda beds has already been suggested in the preceding paragraphs. In origin it is essentially the product of volcanic eruptions in the Central Cordillera, the ejectamenta from which were carried into the valley by the lateral streams coming from this range. During the epoch of these eruptions or just preceding them the valley was elevated somewhat above its present levels, 700 to 1,500 feet above the sea.

It is conceivable that the inclosing mountains, the Central and East cordilleras, were elevated to much higher levels, producing the relief now

FIGURE 12.—*Sandstone saturated with Asphaltum at Base of Honda Series*
The locality is 6 miles south of Mariquita, upper valley of the Rio Magdalena.

found here, and that the *graben* lying between was much deepened subsequent to Honda deposition, as the structure of these beds indicates. This may have been the view intended by Stille,[45] as illustrated in the emended section (figure 8, page 621). The pre-Hondan existence of this *graben* depression is evidenced by the distribution, character, and attitude of the Barzalosa beds, as already shown, on which the Honda rest horizontally, with disconformity. After the accumulation of the Honda beds on the older floor to a depth of 1,000 feet or more, volcanic

[45] H. Stille: Geolog. Studien im Gebiete des Rio Magdalena, v. Koenen Festschrift, 1907.

activity ceased to such a degree that the effects of denudation and erosion overtook those of aggradation, and their activities are still in progress.

The Honda series is here correlated with the marine Pliocene deposits of the coastal districts, as found at Barranquilla and Cartagena. This correlation is based very largely on its stratigraphic position, volume, etcetera, since no fossil evidence of age has yet been found in the Honda beds, although study of their silicified woods may supply it.

Evidences of petroleum.—The Honda beds are known to be petroliferous in a few places at least, to such an extent as to excite the interest of oil men and geologists. Along the valley of the San Filipe creek a few miles south of Mariquita excavations for the railroad have disclosed beds of asphaltic sand and gravel 12 to 15 feet in thickness at the base of the series. These asphaltic deposits are of secondary occurrence, the asphaltic oil having come from other strata beneath in which it has originated. Similar beds occur farther south in the valley, and Dr. Stutzer has described deposits of the same sort at the base of the Honda beds, near the Magdalena, in the district immediately north of the Rio Nare, and asphaltic residues associated also with the crystalline rocks near by which underlie the Honda. In all such cases, however, it is to be supposed that the petroleum originated in older strata, Guaduas or other, underlying the Honda at some depth, since there are no organic materials known in the Honda series itself from which petroleum could have been derived directly. In this respect the Honda resembles the Barzalosa series.

Pleistocene Deposits

Marine terraces

Pleistocene marine terraces are abundant on all parts of the Caribbean coast of Colombia. Not only are there wave-cut terraces above the present sealevel, but there are raised beaches and littoral deposits with corals and recent marine shells, etcetera, over a wide zone along the coast, with inland extensions along many of the rivers. South of Barranquilla, east of the Bay of Cartagena, along the Sinú Valley, about the Gulf of Morrosquillo and the Bay of Arboletes, these terraces and terrace deposits are easily recognized. They do not often occur, however, above an elevation of 50 or 60 feet.

Inland from the coast these terraces can not always be satisfactorily followed along the river valleys on account of the heavy rainfall and the overgrowth of timber and other difficulties of observation. Deposits of the Pleistocene epoch are more easily found. Along the Magdalena there are horizontally stratified clays, silts, sands, and gravels that may be regarded

as Pleistocene alluvium, and the same may be seen along all the rivers. Along the west foot of the Ocaña range, as well as along the foot of the Cerro de La Paz and the spurs of the Central Cordillera, alluvial gravels are everywhere abundant. Rock debris, gravels, sands, and soil cover all the ridges and hills beneath the dense forest growth which they support.

It is in the higher mountains, especially in the East Cordillera and in the upper valley of the Magdalena, that the Pleistocene epoch has left its plainest records, as will be shown in the following pages.

RIVER TERRACES

Hettner has described an extensive system of terraces in the East Cordillera, some of which are much above the present stream levels. They include some that are clearly river-cut and others that are probably the result of contemporaneous aggradation by the same streams. He believes that the number of "boulder terraces" greatly exceeds that of the "rock terraces," cut horizontally into the formations. If this is true, it is probably due in part to destructive denudation of the latter. Terraces of both classes are found at all altitudes in Colombia and are not confined to the mountains or the interior.

In the mountains the river valleys are often deeply cut cañons, as, for example, that of the Rio Suarez, which has excavated its valley in some places from almost horizontally bedded Cretaceous shales, limestones, and marls to a depth of more than half a mile. Along the stretch of this river between Velez and Zapatoca as many as three or four successive terraces may be counted on either side of the valley, which were first cut and then aggraded partly, at least, by stream action. They represent older valley floors of the river which are partly or wholly covered by alluvium, some of which form sloping alluvial plains. The lower of these terraces is usually 40 to 50 feet above the stream and in width is relatively unimportant. The most conspicuous of these lateral terraces is generally 800 to 1,000 feet above the river and often has a width of half a mile. Fuente and Galan and many other villages and numerous farms are situated on this terrace. Still higher, on the sides of the cañon valley, 1,500 to 1,800 feet above the stream, another course of terraces contains villages and farms, as at Guane and Cabrera, the latter at an elevation of 3,200 feet above the sea and 1,720 feet above the river.

Among the fine examples of alluvial terraces in the East Cordillera is that in the environs of Bucaramanga. Hettner describes this as a boulder terrace (Schotterterrasse), but which appears to have been an older valley floor of the Rio Lebrija, developed under drainage conditions

very different from those of today. According to his description, it lies along both sides of the Lebrija at an altitude of 3,260 feet, or 700 to 1,000 feet above the river, which, with its lateral streams, has greatly dissected it. Regarding this plain Hettner says in part (page 50):

FIGURE 13.—*Rock-cut Terrace mantled by Alluvium.*

This view is taken on the east bank of the Rio Suarez, looking northwest, 15 miles southeast of Zapatoca; terrace level about 900 feet above the river.

"Terraces exist also upon the other side of the Rio Lebrija, which had originally been connected with the plain of Bucaramanga. They consist of reddish sandstone and slate, coarse to head-size boulders of quartz, red sandstone, schist, and granite. The alternations of boulders and sand produce an evident stratification; the beds are gently inclined toward the west." . . .

On the eastern slope of the cordillera there is a great system of such terraces, illustrated by those of Labranzagrande and Medina. The latter is described by Hettner in the following paragraph (pages 50-51):

". . .; all the more abundantly are they developed in the broad valley of Medina, near the foot of the mountain, which (valley) they almost entirely fill, and indeed are not connected here with separate streams, but form a broad zone running parallel to the foot of the range, which is crossed by the streams. They fall into two groups, which have different elevations; upon a terrace of the first group lies Medina, 500 meters above the sea; immediately east of it rises the Mesa of Calzon to about 600 meters. Also the road from Medina to Gacheta leads across a great boulder terrace, which is denoted as the 'Mesa del Cura.' Farther south, at Cumaral, these mesas occur immediately upon the Llanos." . . .

In his conclusions (page 51) Hettner states that these "boulder-terraces"

"are only remnants (of boulder plains) left by erosion, which once had spread completely over the valleys, probably at the same time at which in other places existing rock terraces yet formed the valley bottoms. The destruction of these old valley bottoms has been effected by the incision of the rivers, while on the other hand their original development must be attributed to flood waters." . . .

On either side of the upper valley of the Magdalena terraces of alluvial character abound, some of which are well up on the slopes of the Central and East cordilleras. Such an alluvial terrace forms the plain of Pica Leña, sloping from Ibagué, 4,300 feet elevation, eastward to the edge of the mesa above Gualanday, about 2,900 feet elevation. Hettner describes a similar plain covered by alluvium, sloping from Fusagasugá—elevation, 5,640 feet—westward to above the village of Boqueron, where it terminates at about 2,850 feet. It lies along the south side of the Rio Chocho, though at an elevation of 1,000 feet above it. In both cases these elevated plains represent the ancient valley floors of streams tributary to the Magdalena, now possibly elevated by faulting above their earlier level with reference to the floor of the latter. At any rate, faulting is common on both borders of the valley. These examples serve to illustrate the terraces that are found everywhere along the valley borders in the Central and East cordilleras. They range in altitude up to above 10,000 feet above the sea, where true alluvial terraces are not readily distinguished from those of glacial origin. Many of these alluvial plains are much dissected by modern drainage lines, which have cut deep channels across them or along their borders.

It is by subsequent uplift that the streams are able to cut through the older valley floors, which they thus abandon, leaving only remnants of

FIGURE 14.—*Glacio-fluvial Plain*

This locality is at the head of the Rio Suba. It is 15 miles north of Belen, Boyacá. View is taken looking northeast.

them stranded on the flanks of the valley. The total amount of such uplift may be reckoned as more than the difference between the highest residual terrace and the present level of the river. The complete record of this uplift is, perhaps, not decipherable, though its more important pauses are marked by lateral terraces at various altitudes. The present is evidently an epoch of relatively great continental elevation, probably not less than 2,000 feet above the levels maintaining during the time of the highest terraces.

Glacial terraces, glacio-fluvial plains, and even moraines are found in many of the higher ranges, though not below paramo altitudes, generally only above 9,000 feet. On the headwaters of the Rio Suba, some 25 miles south of Onzaga, a paramo plain of glacio-fluvial deposits, now much dissected, extends for 10 or 12 miles along the west side of the river at a general altitude of 10,500 to 11,000 feet above the sea. Hettner describes other such plains and terraces under the snowy summits of Cocui, above the Rio de las Nievas, where Guican,

10,700 feet, lies on the surface of such an one. Stutzer sees in the paramo of Cruz Verde, above Bogotá, 11,200 feet, evidences of glaciation in cliffs and moraines. Such glaciers as existed in Colombia, however, were of the Alpine type and as such were not extensive.

The altitudes under which these glacial and glacio-fluvial deposits originated is not conclusively known. One is apt to associate glacial conditions with mountain elevations much above those of the present. This, however, seems unnecessary, since it is simpler to connect these glacial deposits, terraces, etcetera, in the Colombian Andes in a descending series with the high river terraces extending along their valleys downward from their sources and accordingly not with the present epoch of relatively high altitudes which these mountains have attained in their later history. Glacial conditions here seem to have been the result of climatic changes due to other causes than altitude. The region, however, does not appear to lend itself to an analysis of glacial history such as has been made in other parts of the world.

WARPING OF PLEISTOCENE DEPOSITS

It is not intended in the preceding paragraphs to suggest that the Pleistocene uplifts were everywhere uniform, even though continental in extent. Hettner has given extensive descriptions of the river systems of the Eastern Cordillera and their manifold features, especially within the drainage of the Magdalena. He has shown that the drainage divide between this system and the Orinoco, while devious and much indented, lies along the eastern side of the Plateau, and that the western side, although mountainous, is deeply trenched by the rivers flowing from its interior. These streams for the most part have stretches of steeper gradient and rapid flow, and others of quiet meander through level plains, as is the case with the Magdalena itself. In the latter such conditions are recurrent and in fact have a practical bearing upon its navigation. In the valley above Honda the current is gentle and river boats operate as far as Neiva. Below Honda for more than 25 miles the river rushes through a gorge impracticable for boats, while below La Dorada boats operate to the coast, though not with uniform ease. Stretches of rapid current recur with intervening ones of quiet water. These rapid intervals are well known to the river pilots, though their geologic cause may not be so well known.

Similar intervals of rapid and quiet current appear along most of the larger tributaries of the Magdalena coming from the interior of the Plateau, as the Rio Funza, the Sogamoso, the Lebrija, and the Suba, especially the first two. Within the limits of the Plateau the Rio Funza

and the Rio Sogamoso (Chicamocha) are generally quiet, with many miles of meandering flow. In the past these gentler stretches have been aggraded, while those of steeper gradient have been continuously swept clear and eroded, while coincident changes of level have affected both, but in opposite directions. Such processes of filling and of erosion along the courses of the streams have resulted in the warping of the original planes of sedimentation and in the impounding of vast quantities of alluvium in the intervals of quiet current. These features of the drainage represent the last stages of Pleistocene history, and in truth such action is still in progress.

FIGURE 15.—*East Bank of Rio Magdalena below Rio Sogamoso*
Showing the floodplain of the river in the lower part of the central valley.

EARTHQUAKES

The recurring earthquakes of the northern Andes, as well as of the Caribbean region as a whole, are too frequent to permit neglect in this connection. While no authentic record of these disturbances has been kept in Colombia, their frequency is well known. That they have no connection with vulcanism at the present is evident in the fact that no late eruptions have occurred in any of the relatively few volcanic districts of the northern Andes, although they have occurred in the past.

If they are to be interpreted as orogenic results, then mountain-building here is not yet concluded. In the light of present knowledge regarding major zones of rift in the Andean and Caribbean regions, it may be assumed that movements along them are frequent, and that such move-

ments would require as frequent readjustment along minor lines, and the faulting, folding, and warping found throughout this region may be regarded as the accumulated results of many seismic disturbances in the past. The frequent earthquakes may be referred either to local readjustments or to more remote movements along major lines, but in either case they may represent the magnitude of the ordinary disturbances in normal epochs whose accumulated results we may everywhere observe.

Tectonic Features

General statement

The tectonic features of the nonmarine Tertiary deposits of Colombia have already been partially described. While significant with reference to the development and history of the Andes, they do not indicate their origin, which certainly antedates the Tertiary. Moreover, as a rule, the folding and faulting of these deposits are less impressive and simpler than those of the Cretaceous areas of the East Cordillera or of the marine Tertiary of the north coast.

The structure lines of the Central and East cordilleras, as well as of the Caribbean coast, have a direction of north 20 to 30 degrees east, though transverse lines of folding and displacement are sometimes found. The lateral displacement or offsetting of folded strata is common on the Plateau and has also been observed in the Tertiary beds of the low country and on the coast. Block-faulting in later geologic times is often found and in some parts of the country may be the rule. Stille has shown[46] for the upper valley of the Magdalena an elaborate system of faulting, extending from above Natagaima northward beyond Honda, and in his view the system continues farther. Some of these lines intersect, in a manner to produce block-faulting. However, the valley itself he has described as an interandean *graben,* bounded on the east and west by longitudinal fault-zones, with a downthrow on the eastern zone of more than 2,000 meters (6,560 feet). Concerning the regional extent of this great depression Stille has this to say (page 350):

"It is an extended *graben-sink* of the greatest magnitude in the strike of the range; its length from the juncture of the Central and East cordilleras to the latitude of Ocaña, where the Central Cordillera breaks down, amounts to about 650 kilometers, and we would extend it, as we believe ourselves justified, until, in the depression intervening between the Sierra Nevada de Santa Marta and the Sierra de Perijá, we embrace a strike-length of about 1,000 kilometers. . . . Its width in cross-section between Honda and Natagaima attains about 15 kilo-

[46] H. Stille: Geolog. Studien im Gebiete des Rio Magdalena, p. 350.

meters. The interandean depression of the Magdalena Valley is certainly a fault-block, and the separation of the cordilleras seems to be essentially the interpolation of such."

Faulting along the eastern border of the valley has produced a series of step faults and longitudinal blocks having easterly dips, as already stated. The longitudinal folding of the Tertiary beds along this fault-zone has already been mentioned. The continuity of these structures is sometimes interrupted by transverse faulting, offsets, etcetera. To what extent this block-faulting has affected the nonmarine beds in other districts can not be stated, though it has been observed on the Plateau near Bogotá and at other points.

RELATIONSHIP OF RANGES

Although partly outside the scope of our subject, tectonic studies lead to a consideration of the relationship of some of the mountain ranges of Colombia—a topic but little known. From its physiographic aspect, position, and geologic composition, the Sierra Nevada de Santa Marta is essentially a continuation or outlier of the Cordillera Central. This is apparently the view taken by Stille (page 352) and by others. On the other hand, the Sierra de Perijá, with its westward-facing scarps, may correctly be regarded as a prolongation of the eastern Andes and as continuing the system of faulting so pronounced along the western border of the Plateau. This also is the view taken by Stille, who would align these scarps with that of the Ocaña range and the westward-facing escarpments of the upper Magdalena Valley.

Stille also proposes for the valley of the Cauca a *graben-sink* similar to that of the Magdalena Valley, which in like manner might be extended to the south into the upper valley of the Rio Patia, although in its present aspect this valley is partly erosional.

The regional map of Colombia suggests that the longitudinal valleys of the Atrato and the San Juan rivers, which are in remarkable alignment, have had a similar cause, and the geology of the bordering ranges, as far as known, bears out this view.

While there are many distinct ranges rising on the general base of the East Cordillera, those on its eastern and western borders are the most prominent and continuous. The watershed of the eastern border culminates in the lofty summits of Cocui, with which other ranges align themselves. Although this range is almost entirely composed of elevated Cretaceous sediments, crystalline rocks appear in its northern sector and form a strong connecting link between it and the Sierra de Merida, which is chiefly formed of crystalline rocks. On geological and tectonic grounds,

the Sierra de Merida has been regarded as a direct continuation of the Colombian East Cordillera, although Hettner regards the connections as unimportant. In part he says (page 26):

"Connected with the basin of Cucuta, a depression extends, therefore, transversely across the range and lends to the Cordillera de Merida an individual character." . . .

With the exception of the ranges lying west of the Atrato and San Juan valleys, all the principal ranges of Colombia exhibit a strong eastward flexure on approaching the Caribbean coast. The Sierra de Perijá, for example, is continued in the axis of the Goajira Peninsula, whose geology is continued in the islands off the Venezuela coast, thus remotely relating the basin of Maracaibo with the valleys of the Colombian Plateau region.

Diastrophic History

It is generally conceded that the Guadalupe of the Colombian region, while Upper Cretaceous in age, is not contemporaneous with the latest Cretaceous deposits of Europe and other regions of the world. In other words, it does not represent the close of Cretaceous time itself.

Scheibe has shown that before the deposition of the Guaduas series, here regarded as Eocene, a long epoch of erosion and denudation had acted on the Guadalupe, removing as much as 2,500 feet of its upper strata in many parts of the East Cordillera, as at Tocaima, Tequendama Falls, and other places. From such facts it is evident that before the close of Cretaceous time earth movements had begun in the northern Andes which had elevated these mountains much above the sea, accompanied, doubtless, with much folding and faulting of the strata, subjecting them to denudation, continued well into Tertiary time. Tectonic development, therefore, began on its broader lines with this post-Guadalupe uplift, and the principal axes of folding and of faulting had their inception at this epoch. The *graben* of the Magdalena Valley was outlined, as were also other large structural basins, including that of the Rio Cesar, Maracaibo, and the larger valleys of the Plateau in the East Cordillera, probably that of the Cauca-Patia, and possibly also that of the Atrato-San Juan, near the Pacific border.

In early Tertiary, namely, in Middle Eocene time, subsidence had brought the coastal districts beneath the sea, here as in Peru, and had, perhaps, also deepened the *graben* of the Magdalena to an extent that soon permitted the ingress of the sea into the interior valleys. At all events, the early Tertiary subsidence brought the already denuded mountains into low relief and led the sea inland with the development of three dis-

tinct types of deposits, namely, marine, estuarine, and terrestrial (lacustrine), with the formation of carbonaceous beds and coal veins in each, not entirely contemporaneous, however, since subsidence on the coast preceded that in the mountain areas.

During the progress of Eocene time volcanic activity began or was revived, producing in the Guaduas series intercalations of porphyrite, and in the Canal Zone volcanic breccias and agglomerates, such as are found in the Bas Bohio and Las Cascadas formations, described by MacDonald.[47] Pebbly layers with andesites and porphyrites are described by Bosworth[48] as occurring in the Negritos formation of Peru. This period of subsidence was interrupted, first in the interior of Colombia by an upward movement which closed the Eocene and excluded the Oligocene sea and its deposits therefrom, while it permitted them to succeed the Eocene in the marine provinces. This uplift in the northern Andes was, perhaps, the cause of the heavy deposits of detrital and volcanic materials in the lower Oligocene of the Canal Zone, also described by MacDonald. Eruptive activity during Oligocene time was apparently continued to its close, finally resulting in further uplift and complete expulsion of the sea from present continental areas.

The early marine Miocene deposits of the Colombian coast are usually coarsely detrital, indicating that littoral conditions prevailed here at this epoch, and this evidence is supported by the character of the early Miocene fauna. Subsidence which began in the early Miocene spread inland by stages into the great embayment of the Magdalena, producing successive provinces—marine, estuarine, and lacustrine—and in each its appropriate deposits. The sediments of early Miocene in the interior show evidences of earlier vulcanism, though limited and not continued into its later epochs, which seem to have been characteried by volcanic quiescence rather than activity.

The long interval of Miocene subsidence, sedimentation, and volcanic rest was brought to a close by events of revolutionary character in the northern Andes. Elevation of the mountains, faulting on a vast and cumulative scale, and folding of all earlier formed strata, some of which were already much disturbed, and volcanic outbursts of great violence prove this early epoch of the Pliocene to have been the most actively constructive one in the history of the northern Andes. To the earth movements of the epoch the Andean system probably owes its chief development and orographic relief. This seems also to be the view of Stille,

[47] D. F. MacDonald: Bull. 103, U. S. Nat. Mus., 1919, p. 526.
[48] T. O. Bosworth: Geology and Paleontology of N. W. Peru, 1922, p. 21.

who (page 340) refers the origin of the Magdalena trough to the "later Tertiary time."

What the amount of this early Pliocene uplift was is not fully known, but it was probably differential and not uniformly equal everywhere. Faulting was one of the principal results, much of which doubtless took place along older lines of dislocation, though new ones were probably developed where only lines of weakness had previously existed. That a large part of the general uplift of the Plateau was effected at this time is evidenced by the fact that the Miocene (Barzalosa) series was involved, in some places showing displacements unequaled at any other epoch. According to Stille (page 321), south of Ricuarte the "Honda beds" (probably Barzalosa) have been faulted to an extent of a 2,000-meter downthrow. This is not the maximum amount of faulting on this zone, which in some places possibly exceeds 3,000 meters. These early Pliocene events were later followed by an epoch of denudation, erosion, and the beveling of the upturned edges of the Miocene strata, both on the coast and in the inland basins among the mountains.

Following this interval of denudation came a third epoch of Pliocene history, signalized by volcanic outbursts in the Central Cordillera, to which is due the tuffs and ash beds of the Honda series, as here defined. This volcanic activity was prolonged through later Pliocene time and covered the folded and denuded Miocene (Barzalosa) series with horizontal sheets of assorted volcanic and detrital materials. This volcanic activity of later Pliocene time appears to have centered about the cones of Ruiz, Tolima, and Huila, in the mountains of Colombia, though other centers were probably active farther south in the Andes. Ejectamenta in vast quantities were scattered broadcast over the slopes of the range, some of which was carried down by the streams to find lodgment far afield, as in the upper and central valleys of the Magdalena. Streams entering the upper valley built there the Honda series in its typical development.

The orogenic relief resulting from post-Miocene (early Pliocene) disturbances and uplift seems to have been essentially the same as that of today, except only in absolute elevation, which was probably considerably less.

Following the epoch of vulcanism which closed the Pliocene came one of uplift, denudation, and erosion without volcanic activity of great magnitude. The movements of uplift were recurrent and by impulses and were regional over the mountain districts. Whether this epoch of recurrent uplift belongs properly in the Pleistocene or was later is, perhaps,

debatable, though it is represented by the system of terraces along the river valleys, which may be followed upward into the areas of fluvioglacial deposits high among the mountains. The present altitudes of the Central and East cordilleras are probably from 2,000 to 2,500 feet above those maintaining at the close of the later volcanic epoch, referred to the Pliocene.

While the uplifts of this epoch affected chiefly the mountains of Colombia, they were, nevertheless, felt in the coastal districts, though in a less degree; and here, as among the mountains, they were accompanied by warping of the earlier beds, Pliocene and others.

In the upper valley of the Magdalena the Honda beds are warped and to a limited extent faulted, just as are the contemporaneous marine beds of the coast, though to a less extent. This fact may not be representative of the mountain region as a whole.

In the mountains of the interior the upward movements are chiefly marked by the terraces found along the principal rivers, and in the vicinity of the coast by marine terraces. The last impulse of this upward movement was comparatively slight and doubtless differential. The erosional effects resulting from it are still in progress, especially in the mountainous areas, but more active in the higher mountains.

Some of the earthquakes that have visited the country during the recent epoch suggest that faulting, folding, and warping of the formations are still in progress here, as they are also in other parts of Andean system; but these earthquakes should be interpreted as local effects of crustal readjustments of continental or intercontinental extent and perhaps as representing terminal phases of long-continued action.

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FIGURE 1.—*Geologic Map of Santa Rosa Island, Santa Barbar*

nta Rosa Island, Santa Barbara County, California

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GEOLOGIC SKETCH OF SANTA ROSA ISLAND, SANTA BARBARA COUNTY, CALIFORNIA[1]

BY WILLIAM S. W. KEW

(Read before the Cordilleran Section of the Society January 29, 1927)

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INTRODUCTION

The Santa Barbara Islands, clearly visible from the mainland on a clear day, have been the source of much speculation by geologists regarding the type of rocks and structure occurring on them. In fact, less is known about these islands than almost any other part of southern California. In an early report of the California State Mining Bureau[2] a few remarks

[1] Manuscript received by the Secretary of the Society August 1, 1927.
Published by permission of Vail and Vickers, owners of Santa Rosa Island, and G. C. Gester, Chief Geologist of the Standard Oil Company of California.

[2] Stephen Bowers: Report on San Nicholas Island, Ventura County. 9th Am. Rept. State Mineralogist, California State Min. Bur., 1890, pp. 57-61.
Lorenzo G. Yates: Stray notes on the geology of the Channel Islands. Idem, pp. 171-188.
W. A. Goodyear: Santa Cruz Island. Idem, pp. 155-170.

were made concerning the rocks on some of the islands. Later, A. C. Lawson[3] noted the physiography and rocks of San Clemente and Catalina Islands, and W. S. T. Smith[4] published a paper on the physiography of the islands which, even though the various formations were not described, is the most complete account that they have received. Since these islands have been commonly considered to be largely volcanic in origin, it was with surprise that the writer found that Santa Rosa Island is composed mainly of sedimentary rocks similar to those on the mainland opposite and evidently is an integral part of the same structural basin that existed during Upper Tertiary time.

The geologic work comprises a reconnaissance study by E. D. Lynton, Paul L. Henderson, and the writer during ten days in January, 1926. The trip was made through the courtesy of Vail and Vickers, owners of the island. The U. S. Coast and Geodetic Survey map (number 5202), photostatically enlarged, was used as a base. As this is but a hachured map, the geologic contacts could not be located with accuracy. They were placed as correctly as possible with reference to streams and the more prominent peaks. Particular mention is due to Messrs. N. R. and Ed. Vail and to Mr. C. W. Smith, foreman of the island ranch, for many courtesies and without whose cooperation the work would have been impossible.

Location and Topography

Santa Rosa Island is one of the group of four islands lying about 20 miles off the coast of southern California which are commonly referred to as the Santa Barbara, or Channel, Islands. In size, Santa Rosa Island is exceeded by that of Santa Cruz Island, the largest of the group. It is approximately 14 miles long by 11 miles wide, with an area of about 80,000 acres. The distance to the island from Santa Barbara is 30 miles and from San Pedro 110 miles.

The surface of the island may be classed as semirugged. The northern third has a plateaulike terrain, a wave-cut terrace which is dissected by numerous steep-sided gorges, whereas the other parts of the island are cut by many deep canyons and crisscrossed by rather narrow ridges. Practically the entire shoreline is backed by a precipitous sea-cliff that averages about 75 feet in height. The greatest elevation on the island is 1,562 feet, which is attained on the main ridge near the central part. Erosion has been fairly rapid, due to the fact that there is practically no growth of

[3] A. C. Lawson: The post-Pliocene diastrophism of the coast of southern California. Univ. Calif. Bull., Dept. Geol., vol. 1, no. 4, 1893, pp. 128-139.

[4] W. S. T. Smith: A topographic study of the islands of southern California. Univ. Calif. Bull., Dept. Geology, vol. 2, no. 7.

brush, and this has permitted good exposures of the rocks. In sheltered places a few live oaks and Torrey pines grow, but the main type of vegetation is grass which offers good cattle feed. Water is scarce and, except near the ranch house, all the springs are brackish and most of them are unfit for drinking.

STRATIGRAPHY

GENERAL FEATURES

This island has exposed on it a larger area of Tertiary sedimentary nonvolcanic rocks than any of the Santa Barbara Islands. Most of the rocks on the other islands are of volcanic origin or consist of serpentine, cherts, and metamorphic rocks, which are commonly referred to the Franciscan formation, of probable Jurassic age. The formations identified on Santa Rosa Island range in age from Cretaceous to Recent. All of the rocks except the Quaternary were intruded by a basic volcanic rock during the latter part of the Tertiary period. Beside Cretaceous rocks, there are exposed on the island fairly large areas of marine Tertiary and Quaternary strata. The latter series includes the Vaqueros formation (Lower Miocene), the Modelo formation (Middle Miocene), the Santa Margarita (?) formation (Upper Miocene), and terrace deposits (Quaternary). No Pliocene strata occur on the island.

CHICO (?) FORMATION (UPPER CRETACEOUS)

This formation has not been definitely identified, due to the apparent absence of fossils; but, as its lithology resembles so closely the Chico formation where exposed in the Santa Ana Mountains and in San Diego County, this correlation has been tentatively made. Inasmuch as it occurs unconformably below the Tertiary series, it must be older than the other rocks of the island. Although the contact with the Tertiary beds is, in most places, faulted, their normal unconformable relation can be seen in the region northeast of Ford Point. The Chico formation, which has a total thickness of about 1,300 feet, may be divided into two lithologic divisions, as follows:

(1) A lower part, composed mainly of sandstone. This is a massive, micaceous, well-bedded, medium to coarse-grained sandstone that has an olive-brown color on fresh surfaces, but weathering to a reddish brown. The soil commonly has a distinctly reddish color. The best exposure of this part of the section is on the south point, east of Johnsons Lee.

(2) An upper part, composed of gypsiferous gray and maroon-colored shales containing calcareous sandy beds and concretions. This grades downward into alternating sandy shales and hard, brown sandstones that

in places weather into large concretions. These shales are best exposed in the hills back of China Camp, located at Cluster Point.

MONTEREY SERIES (MIOCENE)

General features.—The Monterey series on Santa Rosa Island appears to be closely allied to the section occurring in Ventura County in the mountains northeast of Fillmore. It represents a continuous period of deposition extending through the lower and middle part of the Miocene period. This section is composed of the Vaqueros (including also the Topanga (Temblor) formation) and Modelo formations. The best continuous succession of this series of rocks occurs in the northwest part of the island, though the Vaqueros individually is known to have a greater thickness in the region north of Ford Point. As on the mainland, this section is in general sandy in its lower part, becoming finer grained above, where it contains the characteristic siliceous shales of the Modelo formation. The thickness of the Vaqueros is approximately 2,000 feet and the Modelo 1,500 feet.

Vaqueros formation (Lower Miocene).—The presence of a number of characteristic fossils, which includes *Turritella ineziana* Conrad, definitely correlates this series of strata with the Vaqueros formation of California. Although beds are present at the top of the Vaqueros section which contain *Turritella ocoyana* Conrad, a fossil characteristic of the Topanga, or Temblor, formation, the latter have been included for convenience with the Vaqueros. At many places in California these beds are delineated as a separate formation and probably would be here had more detailed work been permissible. The Vaqueros varies greatly in its thickness, which is due primarily to intrusions of basalt. The best section occurs along the south and north slopes of the mountains and on the coast north of Ford Point. Numerous small patches occur, associated with the igneous rocks, as remnants broken off from the main mass during the intrusion of this rock.

This formation is essentially a sandstone and is everywhere characterized by the presence of many well-preserved fossils. This abundance of fossils is striking, for large oysters and turritellas occur in huge reefs. The oysters are commonly strewn over the surface and accumulate in large numbers in the bottom of canyons. The Vaqueros is mainly composed of gray sandstones and sandy shales, all of which have a slightly greenish tinge. The lithology of the sediments, together with the abundance of fossils and their littoral type, indicate that the Vaqueros formation of the island was deposited in relatively shallow water and probably represents the south side of a basin of deposition the westward extension

of that on the mainland opposite. North of Ford Point a lower sandstone member having a thickness of about 450 feet is present. It consists of a buff or light-brown, cross-bedded, medium-grained rock which in its basal part contains several pebbly layers about 10 feet thick. The fossils in these layers are peculiar in that they have been altered to calcite. The pebbles in the conglomerate, which is nearly black in color, range in size from one-half to four inches in diameter and consist of well-rounded volcanic and granitic material. At the top of the Vaqueros there is a zone of gray sandstones and sandy shale containing fossil reef beds which represent the Topango, or Temblor, phase of the Monterey series. This zone was recognized by the presence of *Turritella ocoyana* Conrad.

Modelo formation (Middle Miocene).—This series of strata is conformable with the Vaqueros and represents a continuation of the same period of deposition. A separation from the underlying Vaqueros has been made entirely on the basis of lithology, as no fossils were found. The Modelo contains a greater percentage of shales and lacks the fossil reefs. The siliceous shale so characteristic of this formation in other regions is the most distinguishing feature. The total thickness of the formation is about 1,500 feet, which is a small figure compared with the sections on the mainland; these commonly attain thicknesses of over 5,000 feet. The best section of the formation is to be observed in the northwest part of the island, in the vicinity of Cañada Corral and Cañada Soledad. The lowermost part of the section referred to the Modelo consists of about 200 feet of light-gray, laminated, siliceous shale and chert having a conchoidal fracture. This is the part which resembles the typical Modelo formation perhaps more closely than any other. In places it has associated with it a hard, white, tough clay shale which is similar to some phases of impure diatomaceous shale. The greater part of the Modelo which lies above the cherty zone consists of dark greenish gray, laminated shales and sandstones which are quite micaceous. Locally the sandstone beds attain a thickness of several feet, and were it not for their stratigraphic position they might be mistaken for the Cretaceous as exposed in other parts of the island. The shales commonly are interbedded with dark calcareous strata two to three inches thick. Aside from the color of the beds, this section of the Modelo is similar to the lithology of that formation at the type section in Ventura County and in the Santa Monica Mountains of Los Angeles County. On the ridge back of East Point a few thin layers of an acid volcanic rock were observed interbedded with the shale.

SANTA MARGARITA (?) FORMATION (UPPER MIOCENE)

The areal distribution of the rocks referred to this formation and their marked difference in lithology between the greenish sandstones and shales

of the Modelo and the light buff-colored sandstones and extrusive volcanic rocks strongly suggest that it lies unconformably on the Monterey series. For this reason these rocks have been doubtfully referred to the Santa Margarita formation, though no fossils have been found in the formation to make certain this correlation. From the presence of boulders of basalt in the mud-flows which form a part of the formation, the Santa Margarita (?) rocks must be younger than or contemporaneous with the greater part of the igneous rocks intruding the Monterey series. The areal distribution of this formation is limited to the northern part of the island and is almost entirely confined to the region north of the main east-west fault. In the northwestern part of the exposure of Santa Margarita (?) on the island the rocks are largely sandstone, interbedded with tuffs. These sandstones, which are apparently more prevalent near the base of the formation, are of a light-gray color, but weather a rusty shale, due to their iron content. The prevalence of iron in the formation is further evidenced by the number of limonitic concretions which cover the surface of the ground. A characteristic feature of the strata is their cavernous weathering and the formation of steep cliffs in the canyons that cut into the sandstone. Above the sandstones are finer-grained beds which form thin-bedded or laminated cream-colored tuffaceous shales and fine-grained sandstones, which at a distance resemble the shales of the Modelo formation in some parts of California. These shales are particularly well exposed back of the ranch house on Bechers Bay. The volcanic material in the Santa Margarita (?) formation becomes more prevalent toward the east, where it is composed largely of an agglomerate containing numerous boulders of rhyolite and vesicular basalt. This volcanic agglomerate is exposed prominently at Skunk Point and East Point. At the latter place a few rhyolite flows occur at the base of the section. All the strata in the formation are considerably cross-bedded and have the appearance of shore deposits.

TERRACE DEPOSITS (PLEISTOCENE)

These deposits consist primarily of light buff to brown, unconsolidated, cross-bedded sands varying in thickness up to 50 feet, which contain at various places blocks of rock that have been bored by mollusks. At the extreme west end of the island some of the sand has been locally hardened by a deposit of lime. There are two levels of these terrace deposits on the west end of the island, the higher one being about 400 feet and the lower one about 75 feet above sealevel.

INTRUSIVE BASALT (UPPER MIOCENE)

Great masses of basaltic rock occur in the more rugged and higher parts of the island. It is intruded mainly into the Modelo and Vaqueros

formations, though at one place a small area of the basalt was found to cut the Santa Margarita (?) formation. There may have been more than one intrusion, for in places dikes, which have a fresher appearance, cut the main mass of the basalt. The two intrusions are essentially the same in their petrography. The basalt is coarse to fine-grained and locally vesicular, but as a whole it has been deeply weathered, and where cut into by erosion presents a distinctly bedded appearance, which conforms to the dip of the overlying Miocene strata. The beds showing this dip are not of extrusive origin, and it is thought that this feature is due to a variation in texture along the edge of the intrusion which resulted as the molten mass cooled. This igneous rock corresponds closely in appearance, mode, and age to that occurring in many places in southern California, particularly in the Santa Monica Mountains, San Pedro Hills, and Puente Hills.

STRUCTURE

GENERAL FEATURES

The structure of the island is essentially that of an uplifted block deformed by folding and faulting. This uplift is thought to have been produced primarily by the intrusion of basalt. It is reasonable, however, to believe that some moderate folding and faulting existed previously in the Cretaceous and possibly in the Miocene rocks. Like the San Pedro Hills, to which this island may be compared, the intrusion of the igneous rock has arched the sedimentary strata into their present condition. After the basaltic intrusion the island was broken by faulting. In general the rocks on the island have a northward dip, the oldest, or Cretaceous, rocks being exposed on the south side. For this reason it might be assumed that a large fault exists beneath the sea to the south of the island, and that the exposed rocks represent a tilted block faulted along its south side. This supposition, however, was not proved by a study of the geology. If a fault does exist, it must lie some distance south of the present shoreline. The northward dips in the Cretaceous rocks along the shore are probably due mainly to folding rather than faulting. The sinuous trace of the shoreline also does not indicate any definite scarp, nor does the bathymetric map show any marked submarine scarp south of Santa Rosa Island. On the contrary, the sea-floor is gently undulating.

FAULTING

The most important fault on the island is that which practically bisects it from the north side of Skunk Point in a nearly due west direction to the south side of Sandy Point. It is well defined, not only topographic-

ally, but also geologically. (See map.) Prominent fault features occur along its trace, such as a striking alignment of stream channels, low divides, and escarpments. In general the rocks are younger on the north side and practically all of the basalt is confined to the south side. From all indications, this fault is of the reverse type, the south, or higher, side being elevated relative to the north side. The fault may be seen exceptionally well on the north side of the 1,285-foot hill and in Cañada Soledad. That some horizontal movement has occurred on the fault is suggested by the outline of the island itself. Distinct offsets in the shoreline at Skunk Point and south of Sandy Point indicate that the northern half has been moved westward.

Another notable feature along the fault is the arrangement of the stream courses. Cañada Corral has its channel offset for a distance of over a mile, and in the other canyons a similar condition exists. This irregularity may be due either to a horizontal movement along the fault or to piracy of the streams following the fault by those flowing northward. However, coupled with the evident offset in the shoreline itself, which coincides in relative direction and amount of movement with that on the streams, the first explanation appears more likely. This condition also admits of the recency of movement along this fault.

What may indicate vertical movement in Pleistocene time is suggested in the region southeast of Sandy Point. At this place the wave-cut terrace, having an elevation of about 75 feet, extends southward to the fault, where it is terminated by an abrupt scarp. South of this scarp another broad, distinct terrace is present, which has an approximate elevation of 400 feet. Since the scarp along this fault has been cut back but a slight distance by wave action compared to the area planed off in the formation of this 75-foot terrace, it appears probable that the 400-foot terrace was at one time continuous with the 75-foot level and later faulted to its present position. Another bit of evidence in favor of this idea is the narrowness of the wave-cut terrace at the 75-foot level which extends along the coast south of the fault. It appears unlikely that, with comparatively soft material composing the rocks along the coast, a wider terrace would not have been cut here, comparable to that north of the fault. A logical explanation for this condition is that during the cutting of the 75-foot terrace faulting took place which elevated the area south of the fault, and the present 75-foot terrace in this area represents only the work of wave action during a relatively short period.

All other faults are located in the southern part of the island. They have an approximate east-west or north-south direction and only affect the Vaqueros and Cretaceous strata. The fault east of China Camp has

the appearance of a thrust, the Vaqueros overriding the Chico (?) formation. The plane of the fault was not seen, but the surface trace of the contact suggests that it dips northward.

FOLDING

The principal fold of the island is the anticline located on the south side of the northern fault-block. (See map.) This fold has a length of over five miles, extending from Cañada Tecolote to the 1,285-foot hill. The intrusion of basaltic igneous rock on the south half of the island has produced here a large domelike structure involving the Miocene rocks. The arching of this fold is plainly visible in the highest parts of the island, where the rocks have been deeply dissected by erosion. Other small folds occur, but they are of minor importance and merely comprise small wrinkles in the major uplift. In the northwestern part of the island, at Cañada Gallion, a very tightly compressed anticline and syncline have been formed in the Modelo shales. It resembles some of the small folds typically found in this shale on the mainland.

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CONTACT ACTION OF PEGMATITE ON SCHIST[1]

BY G. M. SCHWARTZ AND R. J. LEONARD

(Read before the Society by Professor Grout December 28, 1925)

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INTRODUCTION

Pegmatites are normally small and usually occur in the parent igneous rock, so that cases of contact metamorphism directly attributable to pegmatites are rare. In connection with recent studies[2] of the Etta spodumene mine near Keystone, South Dakota, the writers' attention was attracted by the pronounced contact zone which surrounds this remarkable pegmatite. Several specimens were selected as showing the various phases of the metamorphosed rock and these were analyzed and studied microscopically, with the results noted below.

The writers are indebted to Dr. F. F. Grout for suggestions and criticisms, and to Dr. John W. Gruner for additional rock samples, necessary to complete the work.

GEOLOGIC SETTING OF THE ETTA MINE

The geology of the Etta mine has been described in some detail in the paper cited above. The pegmatite is one of a great series which radiate

[1] Manuscript received by the Secretary of the Society December 30, 1925.

[2] G. M. Schwartz: Geology of the Etta spodumene mine, Black Hills, South Dakota. Econ. Geol., vol. 20, November, 1925, pp. 646-659.

G. M. Schwartz and R. J. Leonard: Alteration of spodumene in the Etta mine, Black Hills, South Dakota. Am. Jour. Sci., vol. xi, 1926, pp. 257-264.

outward into pre-Cambrian schists from the Harney Peak granite batholith, which is also pre-Cambrian.[3] The pegmatite is roughly oval in outline, with diameters at the plane of the lower tunnel of 200 and 250 feet, and with a pronounced indentation on the east side, due to a horst of schist. It is not uniform throughout, but has a narrow outer zone of five feet or more in thickness, which consists principally of muscovite with quartz and feldspar. The grains or crystals have maximum dimensions of a few inches. This outer zone grades sharply to the main body of the pegmatite, which is made up of an extremely coarse mass of quartz, feldspar, and spodumene, with lesser amounts of a great many other minerals,[4] especially columbite, beryl, cassiterite, apatite, lepidolite, and amblygonite. The spodumene crystals are probably the largest known anywhere, as they attain a length of as much as 40 feet.

The Contact Zone

General description

It should be emphasized at once that the schists in which the pegmatite of the Etta mine is intruded have all been subject to more or less intense metamorphism, as a result of the intrusion of the Harney Peak granite. Thus the contact effect here described is in reality superimposed on the effect due to the granite, if one thinks of the granite as having solidified before the pegmatite, or it is a more severe effect if the granite mass and pegmatite were intruded more or less simultaneously. In any event, there is a narrow zone completely surrounding the pegmatite which shows a very decided metamorphosis, and the field relations show very clearly that this was caused by the pegmatite.

The contact zone has been well exposed almost entirely around the pegmatite by the open-pit mining, and also at other levels by various short tunnels which penetrate the knob or hill occupied by the deposit. The zone over which a decided effect may be noted in hand specimens is normally from 5 to 7 feet in width, but at places reaches a maximum of 15 feet.

An upper tunnel, which starts on the hillside in schist and passes through the contact zone and into the pegmatite in the open pit, gives the best opportunity to study the zone in daylight. The exposures in this tunnel seem typical of the more normal and abundant phases of the contact rock, and four of the six specimens studied were obtained there.

[3] For an extended discussion of the geology of the region, and an excellent geologic map, see S. Paige and N. H. Darton, U. S. Geol. Survey Folio 219, 1925.

[4] See G. M. Schwartz: Op. cit.

These specimens represent a gradation from schist to the granular rock at the contact. In cross-cuts from the lower tunnel, notably to the south, there is an alternation of pegmatite and contact rock resulting in a wider zone.

TYPES OF CONTACT ROCK

The rock close to the contact is at most places a friable, finely granular, sugary rock of a grayish to pinkish color, but there are at least two notable variations from this type. On the north side of the open pit the contact zone is well exposed in a cut extending out from the pit and shows a zone 10 feet in width composed of a sugary rock like the above, but containing in addition conspicuous plates of biotite varying up to two inches across; on the east side masses of contact rock are thoroughly impregnated with tourmaline, forming a dark tourmaline schist. This is the only phase in which the schistosity is retained.

Six samples were selected for detailed study as representative types. Number 0, as given in the table of analyses, was taken from an outcrop on the road about 1,000 feet below the mine, and is supposed to be about the type of schist of the contact zone before it was metamorphosed by the pegmatite. There can be no assurance that it corresponded exactly. Analyses 1, 2, 3, and 4 were on rocks from the upper tunnel. Number 1 was from the schist about 12 feet from the contact and 5 feet from the obvious contact zone. Number 2 was from the schist near the rather sharp gradation to granular contact rock. Number 3 was granular rock at the gradation, and number 4 rock directly at the contact with the outer zone of the pegmatite. The tourmaline rock from the east side of the pit was selected, as it represented an exceptional phase with evidence of much addition from the pegmatite.

MICROSCOPIC CHARACTERS

The schist 1,000 feet from the mine (number 0) is a fine-grained gray mica schist. In thin-section it proves to be composed mainly of quartz, muscovite, and biotite, with much dustlike magnetite and ilmenite. There is no feldspar showing twinning, but calculations of a norm indicate as much as 25 per cent. Under high power, numerous biaxial grains showing cleavage may be recognized. These are doubtless feldspar. A few tourmaline grains and a single grain of apatite compose the accessory minerals. The mica is conspicuously oriented (see plate 15, figure 1), as would be inferred from the hand specimens.

The schist 5 feet from the zone which is notably affected by the pegmatite (number 1) is not unlike the schist described above. Quartz is

the most abundant mineral and occurs as granular bands with the grains showing a marked tendency to elongation parallel to the schistosity. Both muscovite and biotite are abundant, but muscovite predominates and the schistosity is especially well developed. Feldspar is about as abundant as in number 0, and calculation of the mode indicates about 25 per cent. Tourmaline and apatite are accessory minerals and zircon occurs as inclusions in quartz.

The schist at the point where it grades to granular contact rock (number 2) is a rusty gray, micaceous schist, much like those described above, except that muscovite occurs sparingly and biotite abundantly, and a few plagioclase feldspar grains showing twinning occur with the quartz. There are numerous grains showing cleavage as in the specimens described above. Calculations indicate about 28 per cent feldspar. Apatite and tourmaline are somewhat more abundant than in number 1. The schistosity is also less marked in thin-section.

The rock about 18 inches closer to the contact than number 2 is distinctly different and belongs to the contact zone (number 3). It is a gray to pink, sugary, and decidedly friable granular rock. Thin-sections show the rock to be composed of a mosaic of quartz, feldspar, and muscovite. The texture corresponds to that termed granoblastic by many petrographers.[5] Tourmaline, apatite, and zircon are accessory minerals. Tourmaline and apatite are notably more abundant than in the rock farther out. There is practically no evidence of schistosity except an apparent orientation of well-developed muscovite in hand specimens. The abundance of feldspar showing twinning is conspicuous. Calculation of the norm indicates over 50 per cent feldspar, mainly the albite molecule.

The rock in direct contact with the pegmatite is represented by number 4. It is a gray sugary rock somewhat less friable than number 3. In thin-section it proves to be composed of a granular aggregate (see plate 15, figure 3) of remarkably fresh euhedral grains of feldspar (plagioclase, orthoclase, and microcline), quartz, and muscovite, with accessory tourmaline, apatite, and zircon. The mode shows about 60 per cent feldspar. Small tourmaline crystals are very numerous, but they do not make up a large percentage. Apatite is more abundant than in the schist farther out from the pegmatite. The rock obviously represents a complete recrystallization of the intruded schist. A poikilitic texture is conspicuous at places in the slides. This is the most abundant phase, as

[5] See, for example, Grubenmann and Niggli: Die Gesteinsmetamorphose, vol. 1, Berlin, 1924, figure 101, p. 430.

thin-sections of different specimens from very close to the contact show similar characters.

The dark tourmaline schist exposed along the east side of the pit contains crystals of tourmaline as much as an inch long. In thin-section this rock shows a remarkable network of tourmaline with small embedded grains of quartz, forming a mosaic texture (see plate 15, figure 4). Muscovite is abundant in parts of the section and is oriented with the tourmaline. Apatite is also important. Microcline, magnetite, and zircon are minor minerals. The very small amount of feldspar is in striking contrast with the large amounts in the other contact rocks.

At the north side an opening from the pit to the hill side exposes the coarse biotite contact rock noted above. This rock is somewhat similar to number 4, especially the sugary texture, but the abundant biotite plates an inch or two across are exceptional. Small tourmaline crystals, quartz, and muscovite are embedded in large crystals of microcline and quartz forming a remarkable poikilitic texture (see plate 15, figure 6). Parts of the rock not showing the poikilitic texture have the granoblastic texture typically developed.

CHEMICAL DATA

Because of the usual conception of a pegmatite as the last and more volatile and mobile parts of a magma to crystallize, the writers expected to find that there had been notable contributions from the pegmatite to the contact zone. To determine the extent of the change in composition of the contact rocks and the elements contributed, six analyses of the rocks described above were made by Mr. Leonard.

On the whole, the analyses revealed less difference than was anticipated between the normal phase of the contact rock and the schists which had not been appreciably affected by the intrusion of the pegmatite. Nevertheless, several points of considerable significance were brought out and these are discussed below.

Ferrous iron, magnesia, soda, potash, water, and phosphorus show a decided change with reference to the contact, as is brought out in figure 1. Soda shows a very marked and lime a moderate increase. This checks well with the development of large amounts of plagioclase feldspar in numbers 3 and 4, which are from the intensely affected contact zone. Potash, magnesia, ferrous iron, and water show a decrease. This may be accounted for mineralogically by the disappearance of muscovite and biotite. The notable increase in soda must be a result of contribution from the pegmatite, and this is somewhat surprising, as the abun-

dant feldspar of the pegmatite is microcline, although smaller amounts of albite are found.[6] Of the lesser constituents, P_2O_5 shows the most decided evidence of contribution, especially in the tourmaline rock. This

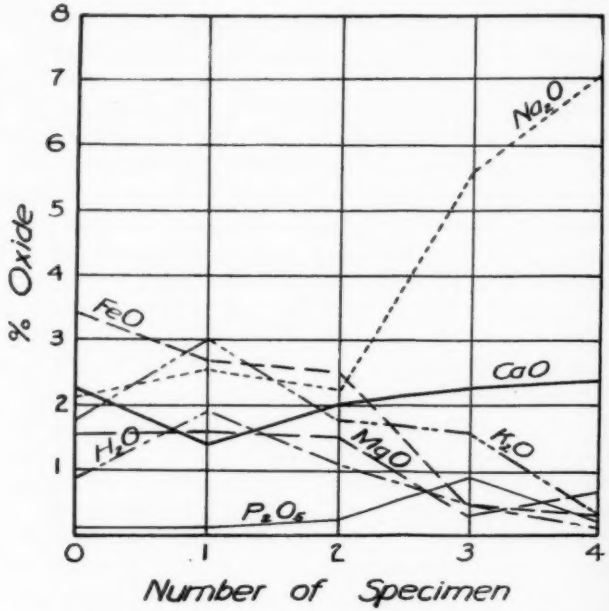


FIGURE 1.—*Plot to show Changes in Composition of the Rocks near the Pegmatite.*

is indicated microscopically by numerous grains of apatite. Boric acid (B_2O_3) also must have been added to form so much tourmaline, but was not determined in our analyses.

[6] See Schwartz: Op. cit., p. 656.

Table of Analyses of Contact Rocks from the Etta Mine

	0	1	2	3	4	5
SiO_2	70.24	66.16	73.75	72.15	72.85	64.81
Al_2O_3	15.33	17.44	12.41	16.21	15.03	16.02
Fe_2O_3	1.01	2.01	1.48	.53	.48	4.75
FeO	3.41	2.68	2.51	.49	.37	.73
MgO	1.58	1.58	1.52	.32	.64	1.50
CaO	2.21	1.39	1.97	2.25	2.35	2.81
Na_2O	2.10	2.54	2.18	5.57	7.10	1.30
K_2O	1.85	3.00	1.83	1.61	.49	.79
Li_2O	.01	.06	.09	.05	.06	.05
H_2O-	.02	.28	.14	—	—	.14
H_2O+	.86	1.96	1.12	.50	.22	.64
TiO_2	.62	.64	.60	T	—	.60
P_2O_5	.15	.13	.28	.86	.77	1.33
MnO	.04	.06	.01	.03	.02	.04
Cr_2O_3	.02	.02+	.01	—	—	.02
SO_3	.37	.12	.12	.17	.05	.19
BaO	.01+	.02+	T	T	—	.01+
ZrO_2	.04+	.02+	.04—	.02	.12	.03
	99.87	100.11	100.06	100.76	100.55	(95.77)

0. Country rock; quartz mica schist; 1,000± feet from contact.
1. Quartz mica schist 5 feet from contact metamorphic zone.
2. Quartz mica schist from just outside contact zone.
3. Sugary rock 5± feet from contact.
4. Sugary rock from contact of pegmatite and intruded rock.
5. Tourmaline schist from contact on east side of pit. Fails to add to 100 per cent, as B_2O_3 was not determined. Usually about 10 per cent in tourmaline.

Referring to the table of analyses, it is at once apparent that silica has undergone no radical change between number 0, a thousand feet from the contact, and number 4, immediately at the contact. There is an apparent loss of silica in number 5, which represents the special tourmaline phase of the contact rock. The large amounts of quartz which form the matrix for the spodumene crystals would lead one to expect the addition of silica, but this apparently did not occur.

There is little variation in alumina, and that is not obviously related to the contact effect. Ferric iron is irregular. It is high in numbers 1 and 2, doubtless due to weathering. It is notably high in the tourmaline rock, contrary to the usual case, but the determination was carefully checked.

Figure 1 brings out the fact that several of the oxides range in amounts only from 1 to 4 per cent in the original rock, whereas they vary from almost nothing to 7 per cent in the altered rock. Perhaps the most significant fact brought out by the analyses is that the composition of an intrusive body is not necessarily indicative of the elements which may be contributed to the intruded rocks. The Etta mine, for example, is justly famous for its huge crystals of spodumene, yet lithia has not been added to the intruded rocks except in very minute amounts. (See table of analyses.) On the other hand, phosphorus (P_2O_5) has been contributed to a noticeable degree, although apatite is an unimportant constituent of the pegmatite. Soda is abundant in the contact rocks and potash unimportant, whereas potash feldspar is by far the most abundant in the pegmatite.

There is a very decided increase in water content in the granoblastic rocks—that is, numbers 3, 4, and 5. This is evidenced mineralogically by a marked decrease in mica and a decrease in anhydrous minerals, such as the feldspars. The senior writer[7] has attributed another case of contact metamorphism which developed the granoblastic texture to a dominance of the heat effect, and the same may be true in this case. At least the general conditions must have favored recrystallization, and differential stress was probably unimportant.

In view of the recent work of Schaller[8] and Hess,[9] one might expect to find more lithium in the contact rocks, since the lithium minerals of the pegmatites are thought to be a result of replacement of earlier minerals. The increase of soda in the contact rocks may be a result of the tendency of albite to develop as a replacement, as emphasized in the papers cited.

Conclusions

1. The zone visibly affected by the special metamorphism due to the pegmatite is very narrow, averaging, perhaps, 7 or 8 feet and not exceeding 15 feet where now exposed.

2. The change from visibly affected rock to that not affected is decidedly abrupt.

3. The contact zone is characterized by a granular rock in which the original schistosity has been at most places completely destroyed. Micro-

[7] G. M. Schwartz: The contrast in the effect of granite and gabbro on the Ely greenstone. Jour. Geol., vol. 32, 1924, pp. 89-138.

[8] W. T. Schaller: The genesis of lithium pegmatites. Am. Jour. Sci., vol. 10, 1925, pp. 269-279.

[9] F. L. Hess: The natural history of pegmatites. Eng. and Min. Jour.-Press, vol. 120, 1925, pp. 289-298.

scopically, the texture is termed granoblastic. At places a striking poikilitic texture is shown, with quartz, feldspar, tourmaline, and muscovite inclosed in grains of quartz and microcline.

4. There is a decided mineralogical change between the schist and contact rock. The biotite and muscovite of the schist have largely disappeared and fresh grains of plagioclase, orthoclase, and microcline are developed. Of the accessory minerals, apatite and tourmaline show a decided increase toward the contact. Biotite and tourmaline characterize special phases of contact rock.

5. The chemical changes are important and are summarized on figure 1. There seems to be no direct relation between the composition of the pegmatite and the material added to the intruded rocks.

Explanation of Plate

Plate 15.—*Micrographs of Schist*

Figure 1.—Micrograph of schist 1,000 feet from the Etta pegmatite. Dark plates are biotite and muscovite, light minerals mainly quartz, and black specks are dustlike magnetite. Plain light, magnified 36 diameters.

Figure 2.—Micrograph of schist 12 feet from the Etta pegmatite. Consists mainly of muscovite and quartz. Plain light, magnified 36 diameters.

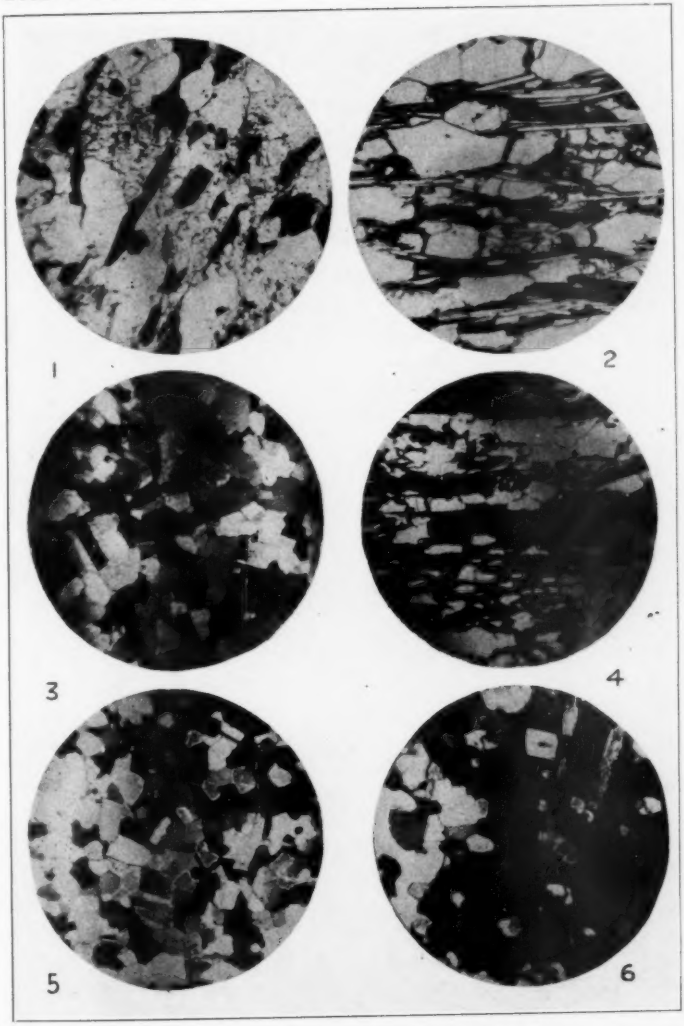
Micrographs of Contact Rocks

Figure 3.—Micrograph of granoblastic rock from the contact. Mainly quartz and feldspar. Crossed nicols, magnified 36 diameters.

Figure 4.—Micrograph of tourmaline schist from the contact. The dark groundmass is tourmaline with grains of quartz embedded. Plain light, magnified 36 diameters.

Figure 5.—Micrograph of granoblastic rock from the contact zone showing poikilitic texture, with quartz and feldspar included in microcline. Crossed nicols, magnified 15 diameters.

Figure 6.—Same rock as above, but showing poikilitic texture, with feldspar, quartz, and muscovite included in a large quartz grain which is at extinction. Crossed nicols, magnified 15 diameters.



MICROGRAPHS OF SCHIST AND CONTACT ROCKS

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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TERTIARY STRATIGRAPHY AND OROGENY OF THE NORTHERN PUNJAB[1]

BY ROBERT VAN VLECK ANDERSON

(Presented in abstract before the Cordilleran Section of the Society)

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[1] Manuscript received by the Secretary of the Society June 2, 1927.

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Summary

The Tertiary of the Punjab is divided into two principal parts, the marine and estuarine Eocene (Nummulitic) system below, and, unconformably overlying this, a great succession of nonmarine beds representing continental sedimentation from the Oligocene to the late Pliocene or early Quaternary. This nonmarine succession, here named the "Nimadric System," includes the Murree and Siwalik series. It comprises over 20,000 feet of fairly well stratified, alternating sandy and silty beds, mainly fine-grained, but coarsely conglomeratic in its uppermost division. It is interpreted as the product of mainly fluviatile, but in part eolian, deposition over fairly flat plains, under a semitropical climate of medium rainfall. The plains extended into the region now occupied by the Himalaya. Evidence of the validity of thickness measurements is afforded by the comparative constancy of individual fine-grained formations, the great thicknesses superimposed in single sections, and by the record here presented of a well 6,000 feet deep. The Nimadric system is divisible into several stages, representing pulsations in the orogenic sequence. The several divisions of the Nimadric decline in thickness southward away from the Himalayan province, which was the source of most of the material.

Structurally, the region is dominantly one of compressional forces tending to fold and thrust the strata southward. The complexity and severity of deformation in the Tertiary beds is greatest in the Himalayan front ridges and tends to decrease away from the mountains. Evidence is afforded by the character, thickness variation, distribution, and structure of the beds that mountain-building and sedimentation during the period following the emergence of the Nummulitic from the widespread Eocene sea went on as follows:

a. Gentle upwarping and wearing down of the Nummulitic in a period preceding that of the oldest known beds of the Nimadric system.

b. Progressive building up of the ancestral Himalayan range, commencing scores of miles north of the present front ridges.

c. Gradual southward encroachment of the mountains by means of overfolding and thrusting, presumably involving from time to time new segments of the submontane province on the south.

d. Progressive downtilting of the plains sector, with greatest subsidence adjoining the mountain front, but with aggradation keeping the surface level constant.

e. Concurrent southward transgression of the basin of deposition of the system.

f. Pronounced rejuvenation and encroachment of the mountains toward the close of Middle Siwalik time; and, finally,

g. Strong deformation during the Quaternary, commencing possibly in the late Tertiary, affecting all portions of the system and producing the structures now in evidence.

The Salt Range was gently elevated after the Eocene, and so remained up to some time in the Miocene; then subsided as part of the basin of deposition of the Siwalik beds, and finally rose during the later Tertiary and early Quaternary and transgressed for many miles southward by means of low-angle thrusting of Cambrian and later beds on the Tertiary.

Introduction

The region here discussed is that portion of northwestern India comprising the Salt Range and the plateau-like area to the north of it, called the Potwar, together with the ridges some 70 miles north of the Salt Range, which bound the Potwar Plateau on the north and which are referred to in this paper as the front or outer ridges of the Himalaya. The material presented is based on observations made during several years' work in this region by the geologists of the Whitehall Petroleum Corporation, Limited, of London, whose directors have kindly permitted the publication of this paper.

The purpose of the paper is primarily to put on record the section penetrated by the 6,000-foot "Jhatla" well drilled by the corporation, to describe in a summary way the great continental Tertiary system in which this well was drilled, and to draw certain inferences as to the conditions that must have prevailed during the time that this thick succession was being formed.

The geologists whose field-work contributed materially to the information here presented were the following: Dr. B. R. MacKay, who spent

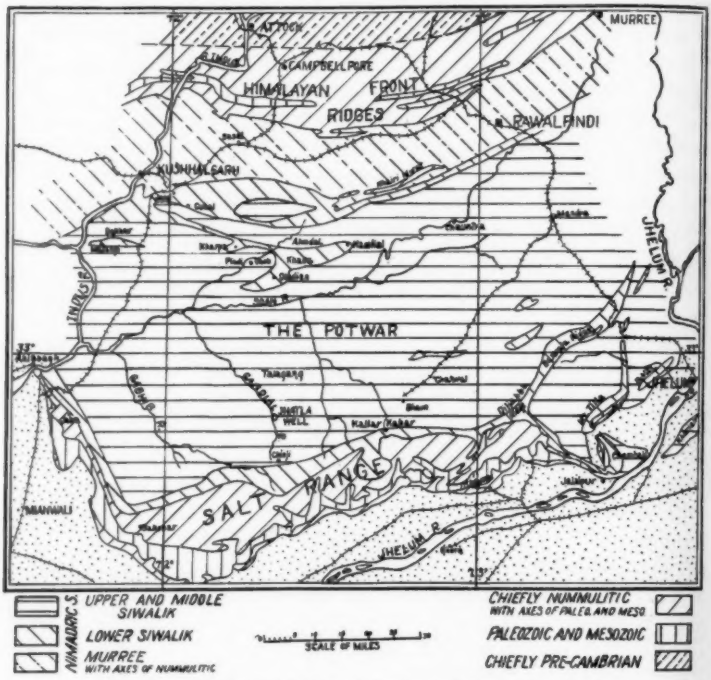

FIGURE 1.—*Generalized Map of Portion of Northern Punjab*

two seasons as chief of a field party in the region here dealt with and whose reports have been a principal source of reference in preparing this paper; Mr. D. Dale Condit, who since 1921 has been the corporation's chief geologist in India; Mr. J. M. Weller, who was assistant to Dr. MacKay and aided him in the preparation of reports; Mr. W. F. Eastman, who kept the log of the Jhatla well during most of the long drilling period and also made numerous careful section measurements; Dr.

J. J. O'Neill, who was chief of a field party in this region for a season; and Mr. J. R. Cox, who spent the greater part of a year in the field. The writer made reconnaisances in the region during the winter of 1920-1921 and again in 1925 and was in touch with the work throughout.

The geology of the Salt Range, the Potwar Plateau, and the outer Himalaya has been the subject of numerous important publications, but the present writer, intending this paper only as a summary based on field surveys, has not attempted a critical review of previous work and conclusions, nor to make a compilation of information from the literature. Possession of the results of earlier workers was of distinct help in carrying out studies in the Punjab, and particular mention should be made of the excellent pioneer work and maps of Wynne.[2] Among other valuable contributions are the papers by Dr. G. E. Pilgrim[3] on the stratigraphy and vertebrate remains; Notes on structure and stratigraphy in the Northwest Punjab by E. S. Pinfold,[4] and Dr. E. H. Pascoe's treatise on Petroleum in the Punjab and Northwest Frontier Province.[5] The latter contains a good bibliography.

Tertiary sedimentary beds occupy most of the region here discussed and comprise the two main divisions which constitute the Tertiary in northwestern India, namely, the Eocene, or "Nummulitic," system and the prodigiously thick nonmarine system, which represents much, if not all, of the Tertiary subsequent to the Eocene, and possibly also part of the Quaternary. There is a notable scarcity of igneous rock both in the Cenozoic and in the older groups, which extend back to the early Paleozoic.

Eocene System

General statement

The Eocene system is partially represented in this general region by a Nummulitic series, varying up to over 2,500 feet in thickness, composed of marine limestone, shale, and calcareous sandstone, with considerable bodies of estuarine and evaporation-basin deposits. The latter types appear particularly in the upper portion and seem to represent in a striking way the variable conditions of inclosed arms of the sea during the marine retreat from this portion of the continent. The stratigraphy of the series has not been thoroughly worked out, but the subdivisions generally accepted in this region, and which appear to hold good here, are a lower and an upper division, as summarily described below.

[2] Memoirs and records of the Geol. Survey of India, 1870 to 1880.
[3] Rec. Geol. Surv. Ind., 1910 *et seq.*
[4] Rec. Geol. Surv. Ind., vol. xlix, 1918.
[5] Mem. Geol. Surv. Ind., vol. xl, Part 3, 1920.

LOWER DIVISION

The lower division of the Nummulitic, frequently referred to as the "hill limestone" because of its prominent part in forming the outer ridges of the Himalaya and the plateau-like summit of the Salt Range, consists principally of massive limestone, interbedded—particularly in its lower portion—with dark shale, variegated sandstone, and locally coaly beds. Its thickness in the front ridges of the Himalaya is reported to be over 1,800 feet, whereas in the Salt Range it has a maximum thickness of 700 feet in the western portion of the range, not far from the Indus. Thence eastward in the Salt Range its thickness progressively declines, until in the ridges that project from the eastern end of the range, toward the Jhelum River, it displays only isolated remnants, and the post-Eocene beds were deposited in places directly on Cretaceous or older strata.

UPPER DIVISION

The upper portion of the Nummulitic of this region, named the "Chharat" by Pinfold, is composed largely of purplish, greenish, and otherwise variegated gypsiferous clay shale and calcareous shale, interbedded with usually thin beds of limestone and fine quartzitic sandstone. A striking feature is afforded by shaly limestone beds composed of a mass of nummulite shells. The above are the characteristics as displayed in the main belt of outcrop of this division along the northern border of the Potwar Plateau.

Another main belt of outcrop, of beds probably the equivalent, and consisting of brick-red, pinkish, purplish, white, and variegated highly gypsiferous and saline clays, calcareous and dolomite shale, etcetera, with huge masses of rock-salt and gypsum, occurs almost all along the southern foot of the Salt Range. These constitute the famous "salt marls" which gave the name to the range and were formerly believed to be Paleozoic or older because they underlie beds of early Paleozoic age. As inferred by several later writers, however, and as shown below, they are with little doubt part of the Nummulitic series beneath a huge overthrust.[6]

In the northern belt the upper division of the Nummulitic series comprises a thickness, as recorded by Pinfold, of about 500 to 900 feet. In the "salt mari" belt the thickness is difficult to determine, owing to surface incrustation and because the base is hidden beneath the plains, but it appears to be considerably over 1,000 feet. The salt mines reveal

[6] An interesting discussion of this and hypothetical alternatives to explain the puzzling problem of the "saline series" and its position is given by Pascoe in his memoir previously cited.

individual beds of pure salt over 100 feet thick and the aggregate of pure and impure salt deposits amounts to several hundred feet.

PROOF OF SALT RANGE OVERTHRUST

The southern escarpment of the Salt Range faces the plains of the Punjab and displays one of the world's most remarkable sections. At the base is the gaily colored mass of the saline stage, and overlying this in successive upward steps, formed by beds dipping moderately northward and excellently exposed, there rises a sequence of diversified sedimentary formations representing numerous periods from the Cambrian to the Miocene. Concordantly beneath the oldest fossiliferous zone (the marine "Neobolus beds," Cambrian), and lying upon the "salt marls" is a zone, several hundred feet thick, called the "purple sandstone." This is undoubtedly the oldest member of the Paleozoic present here. Except for numerous faults, many of which, it is to be noted, are southward thrusts, the upper portion of the "purple sandstone," as well as the higher strata, is little disturbed. In the lower 200 feet or so of the "purple sandstone," however, signs of disturbance progressively increase downward, and the basal 50 to 100 feet is a zone of severe shattering, showing that this horizon has been a locus of crushing and brecciation. The highest portion of the "salt marl" stage immediately below is slickensided and squeezed and the contact is a discordant one. The overlying horizon, in spite of brecciation, is very persistent. The underlying formation is likewise remarkably continuous, but a close examination of the contact between the two shows that the "purple sandstone" zone rides at different points on different horizons of the "salt marls." Moreover, the latter are locally overridden by higher members of the superjacent groups.

These relations indicate that the Paleozoic and Mesozoic mass has been overthrust upon the saline stage. The contact dips northward beneath the Salt Range, approximately parallel with the bedding, but, if anything, at a somewhat lower angle, and is evidently the plane of thrust. The continuity of the "purple sandstone" zone and the "salt marls," one superimposed on the other in such manner along most of the range, gives a strong semblance of a regular stratigraphic sequence and makes this a puzzling and very noteworthy example of bed-thrusting. The fact that the highly incompetent and plastic gypseous and saline deposits would afford an ideal zone for a thrust to be initiated in and to move on doubtless explains in part the persistency with which this formation is the basement beneath the overriding mass.

The Paleozoic and Mesozoic beds, however, do encroach on still later

strata toward the eastern end of the Salt Range. Near Jalalpur the "purple sandstone" zone lies with similar attitude on highly disturbed Siwalik beds, in a relation interpreted by the writer as one of overthrust, thus affording confirmatory evidence of the great thrust or, rather, group of thrusts represented by the range, as well as of the conclusion drawn later in this paper from other data, that the thrusting is late Tertiary or Quaternary in age.

In addition to the structural indications above cited, there is evidence that the age of the saline stage is far less than that of the strata overlying. In the gypseous beds below the "purple sandstone," the writer found the following evidences of the posterior age of the "salt marls," and therefore confirmation of the overthrust.

a. Calcareous and siliceous shales closely resembling the organic shales of the Nummulitic series, even though the traces of organisms which doubtless once existed have been obscured by siliceous and dolomitic replacement.

b. Carbonaceous and other shales that could hardly be conceived as having preserved their Tertiary lithologic character had the beds suffered the lapse of time and undergone the degree of induration, moderate though it be, which has affected the Paleozoic strata.

c. A slight impregnation with petroleum, such as characterizes the Nummulitic and is not known in any pre-Tertiary strata in this part of India.

d. Poorly preserved impressions of leaves of a Tertiary or, at earliest, Mesozoic type.

The Tertiary leaves referred to in *d* were found in well-bedded and laminated calcareous shale in the upper part of the saline stage in Kheura Gorge. Dr. Ralph W. Chaney, of the Carnegie Institution, who kindly examined them, writes as follows:

> "The specimen clearly contains fragments of several specimens of dicotyledenous leaves. This places their age as not older than Lower Cretaceous when the first Dicots appeared. One of the leaves is very probably oak *(Quercus)* and its size and margin strongly suggest the Oligocene species *Quercus clarnensis* from western America. It is of interest to note that I found a closely related species in the Oligocene deposits of Manchuria. Your specimen is almost certainly of Tertiary age."

The post-Jurassic age of the basement stage of the Salt Range being thus established, it is clear that the overlying mass of the range has been thrust in a general southward direction on it. The movement along the principal thrust-plane must amount at least to several miles. There also remains no reason to doubt the equivalence of the "salt marls" to the

similar deposits of known Eocene age in the Punjab and Northwest Frontier Province, the only reason for doubting this having been their position beneath the Cambrian.

Nimadric System

The post-Eocene Tertiary is a picturesque, even though somewhat monotonous, alternation of varicolored sandy and silty, and to a lesser extent conglomeratic, beds of a fluviatile character. Whereas the Nummulitic series was formed in an epicontinental marine basin that included much of the area subsequently occupied by the Himalaya Mountains, the thick succession of beds that overlies represents continental sedimentation on plains at the foot of the ancestral Himalayan Range. This range was partly composed of the uplifted Nummulitic, as shown by materials in the overlying beds derived by erosion from that series. The historical and structural break between the Nummulitic and the unconformably overlying strata bears evidence of being the major one in the Tertiary of this part of the world. From their rich vertebrate fauna these subsequent strata have been correlated by Dr. Pilgrim and others with the whole of the Pliocene and Miocene and probably later Oligocene. It seems not unlikely that beds belonging to the same system may be found which date even farther back, and the upper members may reach into the Pleistocene.

Although showing variations in color, mineral grain, and the grouping of beds at different horizons, this post-Eocene succession is essentially one system of deposits of a fairly homogeneous type, representing sedimentation on floodplains under a set of conditions on the whole remarkably constant. Being at least in broad lines a unit, it is awkward not to have a single name for the whole system. The designation "Sub-Himalayan," which was applied to the Tertiary beds by Medlicott and other early geologists in India, would be appropriate as a means of referring to this post-Nummulitic system, owing to the genetic relationship of the deposits to the zone of depression at the southern foot of the great mountain arcs of India. Unfortunately, the term was used to include not only this system, but the Nummulitic as well. It is, therefore, unavailable as a designation for a portion only of the Tertiary sequence.

The name "Nimadric" is here proposed for the whole of the great system in question, which represents the period of continental sedimentation after the withdrawal of the sea from this northern portion of India up to the time near or soon after the close of the Pliocene, when the system as a whole had become folded through the period of major deformation that left it essentially with its present structural outlines. The

name is a compound of "Himadri," meaning snowy range (from "hima," snow, and "adri," mountain), with the Sanskrit prefix "ni," meaning under, downward, or nether. The elision of the syllable "hi" is in keeping with similar elisions frequent in Sanskrit. The name "Himadri" was used by the ancients as an alternative for Himalaya (from "hima," snow, and "alaya," abode) and its use in the present context seems appropriate, as suggestive of the ancestral nature of the mountains from which the sediments were derived and at whose foot the system was layed down. It may be noted also that, for reasons brought out more fully later in this paper, the plains over which these sediments were spread must have been situated in part within the latitudes now occupied by the outer Himalayan ridges or ranges. These southern ridges grew in part by involving portions of the plains deposits in the frontal mountain structures and in part by overriding on strata of this system. Thus, in a double sense, the prefix "ni" in the name here given connotes the subjacent relationship that this system bears to the Himalaya and its related ranges, with the Indo-Gangetic border of which these deposits are coextensive.

By present usage different parts of the Nimadric system are referred to by two or more names, the "Siwalik" for the upper portion, representing the period from about mid-Miocene to the end of the Pliocene or later, and, in the particular region here treated, the "Murree" for the lower portion. Southeastward, in the Simla region, the approximate equivalent of the Murree is designated in two divisions—the "Dagshai" below and the "Kasauli" above. No precise line of demarcation is known between lower and upper portions of the Nimadric system, and in the region here treated there appears to be conformable gradation throughout. Such general continuity is probable, notwithstanding the likelihood that this relationship was locally and from time to time disturbed, especially adjacent to the ancestral mountains, by deformational forces affecting the beds while accumulation of the system was going on.

Uplifting of the earlier portion of the system along the mountain border previous to the deposition of the Siwalik is suggested, though not proven, by the failure to find Siwalik beds infolded with the Murree in the compressed structures of the present Himalayan foothills, north of a line between Rawalpindi on the east and the Indus a little north of Kushalgarh on the west. But the Murree may be observed overthrust on the Lower and Middle Siwalik in several areas not far south of that line, and the character of the Siwalik members folded and faulted in with the Murree there is not such as to indicate that this was at all near the northern limit of their basin of deposition. At least the lower

and middle divisions of the Siwalik were deposited much farther north, and their absence from view in that direction is to be explained by faulting and by the profound erosion which has truncated the northern region. Hence no unconformable relation between Murree and Siwalik is in evidence. There are suggestions of local unconformable overlap of Upper Siwalik on earlier Siwalik beds, and other features occur lower in the system that may be interpreted as indicating minor unconformities. None of these features, however, is out of harmony with the conception of continuous continental sedimentation within this general period and region of deposition. In the writer's opinion, any unconformities that exist within the system are entirely subordinate in importance to the erosional unconformity of almost continental significance which separates it from the marine Eocene. The basal beds of the system lie variously on different horizons of the Nummulitic series, at least hundreds of feet of the latter having been locally eroded away prior to the deposition of the Murree. In places a slight discordance of dip and truncation of the Eocene beds can be seen at the contact, and there is characteristically a basal zone of the Nimadric system containing subangular fragments derived from the Eocene.

Some of the early workers in Indian geology regarded the Murree series and its equivalents closely related to the Nummulitic beds and conformable with them. The Nummulitic and Murree were therefore grouped together as early Tertiary under the joint name "Sirmur" and set off from the later Tertiary or Siwalik. Among the principal factors leading to this classification apparently were:

a. The close association of the Murree and Nummulitic beds in many compressed structures, making them difficult to separate and giving them the semblance of intimate relationship.

b. A certain similarity in purplish, greenish, and other colors between the Murree and the estuarine phases of the Nummulitic.

c. The occurrence in the lower Murree beds of nummulites derived by erosion from the former series, which led to confusion.

Even though these factors are now known to have no validity as a basis for grouping the two together, the concept, once established and dignified by a name, tends to persist. The name "Sirmur" represents an entirely unnatural grouping and should be discarded. The more natural and significant classification is to group the whole of the continental system together, as done in this paper, and to draw the main line of separation between it and the Nummulitic. A valid basis for this classification is afforded by the major unconformity at the base of the Nimadric, the relative homogeneity and continuity of this system, and

finally the essential contrast in the nature and origin of the deposits in the two systems so separated.

The Nimadric system, where measured in the regions of its most complete development, in the northern and central parts of the Potwar Plateau, has a thickness of at least 20,000 feet. In fact, the maximum thickness would appear to be in excess of 23,000 feet. The major lithologic zones are recognizable from place to place and are susceptible of fairly close measurement, owing to the clear stratification between alternating beds of different grain and color. One is inclined to be skeptical of thicknesses when they mount to such huge totals, but a study of the region convinces the observer that the measurements closely represent the true vertical thicknesses and give a reliable gauge of the depth of subsidence in the deeper portions of the basin of deposition. It is inconceivable that strata of these fine-grained types, comprising stages traceable with comparatively consistent lithologic characters over areas of thousands of square miles, could have been deposited otherwise than on fairly flat surfaces, over which each member was widely spread and, in the aggregate, vertically built up. The presence of several or all stages of the system in single steeply tilted and horizontally short sections and their repetition with similar thickness on the opposite flanks of the same structures, as well as in other structures at a distance, gives opportunity for verification of the measurements. And similar verification is afforded on a less extensive scale by occasional vertical sections where the beds are horizontal.

An interesting result of the Jhatla well is the close confirmation which this deep boring gives of the thickness of certain stages as measured on the surface. The well penetrated vertically through nearly 6,000 feet of these beds where they lie almost horizontally, and the thicknesses checked closely with the surface measurements of the same portions of the system made in near-by districts where they are upturned.

One of the most complete sections is to be found within 20 miles southwest of Rawalpindi, on the Khairi-Murat Ridge, and thence southeastward into the valley of the Soan River, where in a distance of 11 to 15 miles across the strike a thickness of 18,000 feet or more may be measured. Here all the major divisions of the Nimadric system are superimposed one on the other. Owing to disturbance of the lower portion, the measurement is not complete, and there is no assurance that the uppermost beds exposed in the Soan Syncline include the youngest members of the system.

A notable feature with relation to these great thicknesses, clearly brought out in successive section measurements southward away from

the Himalaya front, is that a progressive thinning of the members takes place in that direction. For instance, the Murree beds, which have an undetermined thickness of at least 5,000 feet, and probably much more, along the border of the mountain province, thin out to the vanishing point within less than 60 miles to the south. Similarly, the Lower Siwalik division thins progressively within a distance of 50 miles from 6,000 feet or more to about 2,700 feet. The middle and upper divisions of the Siwalik also become reduced to the southward, their combined thickness (in single sections) declining from 9,000 feet or more to approximately 6,000 feet within the same distance. Sections of the Siwalik as a whole lose between 40 and 50 per cent of their thickness between the northern and southern parts of the region, and if the reduction of the Murree be added the total loss of thickness may be conservatively stated as more than 10,000 feet.

In the same southward direction a tendency is noted for the average coarseness of the deposits to decline moderately, and for siltstones to assume a somewhat more important rôle in the aggregate. This tends to confirm other evidence that most of the material was derived from the north. However, variations in coarseness also occur laterally and locally, and it would require a very detailed analysis to reconstruct the channels and areas of coarser and finer sedimentation.

A characteristic and well-known feature of the system, and particularly of the Siwalik portion, is the abundant occurrence of fossil vertebrate remains. A great variety of teeth and bones, some of large proportions, are scattered through the sandy beds, and especially in the "pseudo-conglomerate" and true conglomerate zones. A significant feature, indicative of the fluviatile nature of the deposits, is that these remains show the effect of dispersal and wear prior to being buried. Remains of palms and other plants are found scatteringly, generally in a poor state of preservation, this condition being also indicative of comminution by streams rather than deposition of the sediments in quiet bodies of water. Fossil wood is common, especially so in the Kamlial stage of the Lower Siwalik. Further brief reference to the fossils will be made in the section dealing with Tertiary history.

Tilted Pleistocene Gravel

A discussion of the various Quaternary deposits is not within the scope of this paper, but mention needs to be made of the fact that there is a formation of fluviatile gravel and boulder beds, referable with little doubt to the Pleistocene, which appear to be unconformable on the Siwalik and which have been, locally at least, considerably deformed.

Such beds attain a thickness of several hundred feet. In the zone of deformation, at the southern foot of the hills of Nummulitic limestone and Murree beds northwestward from Rawalpindi, deposits of coarse boulders apparently belonging to this formation are locally found tilted to the vertical. It remains to be demonstrated whether or not this Pleistocene formation should or should not be included with the Siwalik as a final stage of that series.

Lithology of the Nimadric System

Sandstone and siltstone

Throughout this system the beds are of a type which one associates with subaerial deposition. The main constituents are friable and frequently cross-bedded sandstones composed of fine to medium-sized grains, and alternating with these, or grading vertically and laterally into them, more dense beds composed of a mixture of gritty and clayey silt. Neither of the conventional terms, clay or shale, conveys a true picture of the latter beds. These have features of both clay and shale, and yet their dominant type is distinct from either. Although the finer phases and occasional lenses approach true clay, most of the deposit differs from clay in characteristically containing minute gritty grains, usually making up a major proportion of the volume, and in being in part indurated. It differs from shale in having a massive character which is wholly predominant over the occasional lamination. The term "siltstone," describing its correlative nature with sandstone, is more appropriate and will here be used.

The bulk of the siltstone is found, on washing, to consist of a fine powder of quartz grains mixed with grains or dust of many other materials, variously colored by iron staining. There are all gradations of texture from siltstone to the sandstone. The typical material of the latter is a gray sand composed of angular to subangular and poorly sorted grains of quartz, feldspar, mica, and many other materials of varied colors, commonly with a fine-grained matrix. This ensemble, having a kaleidoscopic appearance under the lens, is characteristic of the system. The greater portion of the sand grains range from a minute fraction up to one-half millimeter in diameter, the grains of diverse size and material being indiscriminately mingled. It is comparatively rare to find sandstones with grains, except those of mica, ranging to over two millimeters in diameter, and even in these the coarser grains are in a minority.

The siltstone beds do not, for the most part, have the hardness ordinarily connoted by the word stone. They are apt to be tough rather

than hard. In part they are little more than dry compacted silt, but again they are cemented and hard, and there are all gradations of induration between. Much the same may be said of the sandstone, which locally is soft, although in general it is semi-indurated. The fine-grained sandstones show a tendency to be more indurated than the coarser. The hardness of individual beds, both of the sandstone and the siltstone, varies greatly from place to place, and a characteristic feature is the occurrence of pronounced induration in irregular ledges, lenses, and nodules in the midst of friable or even incoherent material. Embedded in the siltstone are often found nodules, comparable in shape with small potatoes, and smaller pellets, composed of the same material as the matrix but harder, due to a concentration of calcium carbonate. The latter is present in practically all of the beds and in some acts as a tight cement. Iron salts are also abundant, acting as cementing agents as well as coloring the sediments. Generally speaking, the average hardness of the beds increases the older they are in the Nimadric sequence. Much of the sandstone of the lower (that is, Murree) portion of the system is so indurated as to make a good building stone.

The varied coloration of the strata and the alternation of the deeper-toned beds of fine grain with the generally lighter-colored sandstone layers lends a gay aspect to the outcrops, especially in this semiarid region, where the structure is displayed in picturesque relief. A fact worthy of mention is that sandstone beds often partake of the deeper coloration of the siltstones close to their contact with the latter. It is interesting to note that the intensity of coloration gradually decreases upward in the Nimadric system, from the purplish and maroon shades of the lower portion to the prevailing whitish gray and straw and faintly reddish tones of the uppermost division.

The stratification afforded by the alternating massive sandstone and siltstone beds is conspicuous, and one is usually able to trace for long distances the clear-cut demarcation between the sandstone layers, which weather into prominence owing to superior resistance, and the more deeply colored and indented siltstone beds. It is also common, however, to find one type changing vertically or laterally, sometimes quite abruptly, into the other, and one can not rely on any individual bed continuing unchanged in thickness and character beyond the range of vision. Nevertheless, some of the beds are remarkably persistent and traceable for over a score of miles. Throughout the system cross-bedding is a notable and characteristic feature of the sandstone, and to a lesser extent it may be observed in the siltstone as well. For the most part the beds may be considered as lenses varying from a few feet up to a few miles in lateral extent.

The thickness of different beds varies from a fraction of an inch up to over 100 feet, and occasionally massive bodies of sandstone attain a thickness of two or three hundred feet, but the general rule is for an alternation from sandstone to siltstone, or *vice versa,* to take place every few feet. In addition to the bedding planes, stratification lines are often in evidence through the irregular hardening of layers. Indications of cut and fill along old minor stream channels are not infrequent.

A feature commonly noted is the depositional inclusion of irregular pockets, plates, or lumps of silt or clay in the sandstone, frequently oblique to the bedding, and the siltstone beds themselves locally contain pebble-like inclusions of similar material. These features present a partial gradation into the type of deposit next to be described.

INTRAFORMATIONAL CONGLOMERATE

Beside the sandstone and siltstone, a very characteristic deposit termed "pseudo-conglomerate" occurs in beds and irregular cross-bedded lenses scattered throughout the system. To convey an idea of the relative abundance of this sedimentary type, it may be estimated very roughly that something on the order of 7 per cent of the system has a "pseudo-conglomeratic" character. The deposit is most commonly composed of a sandy matrix containing lenses of siltstone, and full of a variety of small, pebble-like inclusions of siltstone and less often sandstone, of the same types as those forming the system itself and with little doubt derived from it. These intraformational inclusions show a wide range, from pebbles and subangular rock pieces that almost certainly have been rolled to angular fragments, usually of a flattish shape, which appear to have been already consolidated prior to being deposited in the matrix; to pellets and nodules that suggest concretionary character, and to irregular lenses as well as inclusions of a fragmental shape that appear to be depositional. The inclusions are apt to be more indurated than the material of the system as a whole and are often limy and ferruginous. They are also apt to display more pronounced coloration than the matrix, commonly showing purplish, reddish brown, and yellowish colors. The matrix itself is usually indurated with calcareous cement. In addition to the inclusions above mentioned, there are in some of these deposits scattered grains and pebbles of foreign rocks of a size larger than common in the adjacent beds. One common phase of the pseudo-conglomerate is composed of calcareous sandstone or siltstone full of hard pellets about 2 to 5 millimeters in mean dimension. These pellets are of gray to yellowish and reddish brown limestone or calcareous siltstone and ochreous material. The lenses of pseudo-conglomerate range up to many

feet in thickness and at least hundreds of feet in length and they commonly contain vertebrate bones and teeth.

This strange type of deposit presents numerous interesting problems deserving special investigation and discussion. The writer believes that it represents frequently recurring times and places in which beds in the system were subjected to fairly prolonged exposure, to surface concentration of cementing agencies, and to drying and cracking, with the resultant reworking, transportation, and redeposition by wind and running water. Exposure of parts of the systems was very likely due both to local contemporary deformation and to local interruptions in the process of aggradation.

TRUE CONGLOMERATE

A feature of great interest in the Nimadric as displayed in this region is the relative scarcity of true conglomerate or even coarse-grained sandstone. Such deposits are abundant in the Upper Siwalik, but between that and the basal conglomerate of the system deposits of grits or pebbles derived from foreign rocks are present only in small proportion, scattered at wide intervals through the many thousands of feet of medium- and fine-grained beds, and accumulations of boulders or rubble such as one associates with subaerial piedmont deposits are absent. Lenses and stringers of water-born pebbles of crystalline rocks, of Nummulitic limestone, and various other rock types occur at several horizons in the upper part of the Middle Siwalik and in the Lower Siwalik (both Kamlial and Chinji) beds, but such deposits are small in comparison to the bulk of the fine-grained beds. This, taken with other features of the system, indicates that the beds were in the main spread out over level-lying plains, many miles from the hills or mountains that yielded their materials. Dr. B. R. MacKay discovered in the Middle and Upper Siwalik gravelly lenses cobbles that had planed surfaces and angular forms evidencing glacial abrasion. These may indicate that the region from which they were derived was one of high glacier-bearing mountains, comparable with the Himalayan range of today; or, as appears likely, they may have been derived from the boulder beds of the glacial Permo-Carboniferous series, which outcrops extensively in the Salt Range and Himalaya.

The upper few thousand feet of the system (the Upper Siwalik) are characterized by abundant gravelly zones and lenses ranging in coarseness up to boulder beds with boulders as much as a foot in diameter. In these occur abundant cobbles or fragments of limestone derived from the Nummulitic series, in addition to a great variety of other rocks.

Divisions of the Nimadric System

General Statement

The following is a brief summary of the main subdivisions of the system, commencing with the oldest and omitting reference to common features already discussed. The separation into two main series, Murree and Siwalik, is followed for convenience and in order to conform with usage. It is to be noted, however, that the horizon at which a division is to be made between these two is indefinite and a real separation of the system into two series remains to be substantiated by stratigraphic evidence. Paleontologists report a great faunal break between the two, but the fauna known from the Murree is from its basal portion, and there are thousands of feet of intermediate beds for which faunas are not yet known. Probably a better classification can eventually be made by taking the whole system as a unit and dividing it into stages. There is no certainty that a dividing line can be found between Murree and Siwalik of more significance than the lines or, rather, gradational zones of change between various stages. The line now assumed as the top of the Murree and base of the Siwalik is, if anything, less significant than the one, for instance, between the Kamlial and overlying Chinji stages, presently to be mentioned. If a real break in sequence occurs between Murree and Siwalik, it should probably be looked for considerably lower down than the line now assumed.

Murree Series

The basal portion of the Nimadric system, where observed in the belt along the foothills of the Himalaya, consists of a variable zone about 200 feet thick, composed largely of brown, ochreous sandstone with subordinate beds of siltstone and "pseudo-conglomerate." Locally, and especially at the very base, it contains abundant nummulitic and occasional other fossil shells, evidently derived from the Eocene beds, and also contains pebbles, cobbles, and fragments of Nummulitic limestone and other rocks. Locally a conglomerate of shale flakes of the "pseudo-conglomerate" type lies directly on the Eocene and assumes the rôle of a basal conglomerate.

Succeeding this basal zone come thousands of feet of strata, consisting mainly of massive maroon and purplish brown sandstone interbedded with thinner beds of purplish siltstone. The sandstone beds are resistant and form prominently outstanding ledges and escarpments. Occasional sandstone beds are soft and are of a light bluish green, brown, or other color. Sandstone forms the bulk of this division.

In the upper part of the sequence called Murree, in apparently gradational relationship with the beds both below and above, comes a softer and more predominantly silty stage, at least some hundreds of feet thick, composed of gray, reddish, and purplish siltstone interbedded with gray and greenish gray sandstone.

The Murree beds, with locally infolded members of the Nummulitic series, form a continuous belt from 12 to 16 miles wide, fringing the northern side of the Potwar and separating the areas of Nummulitic and older rocks on the north from the Siwalik-covered region to the south. This belt being one of severe compression, the Murree beds doubtless owe much of their induration to the deformation undergone here. Beds ascribed to the upper part of the Murree come to the surface in a few isolated structures farther south and have a much less indurated character. It is probable that the difference in hardness between typical Murree and typical Siwalik, which forms one basis for their separation into series, is due more to the difference of geographic and structural position of their area of outcrop than to any great break between them.

The total thickness of the Murree series is difficult to make out, owing to the close folding and severe faulting that it has undergone in the piedmont belt where it is best exposed. Subsequent work affords no basis for altering Wynne's early estimate of 5,000 to 8,000 feet. As already mentioned, the series thins southward and lenses out entirely in places on the north flank of the Salt Range uplift.

With reference to the nummulites in the base of the Murree, it is clear that these fossils come from the beds of the Nummulitic series and represent a process of weathering and reworking of the material of the basement on which the Murree deposits gathered. It is characteristic of the Nummulitic beds of India and elsewhere, especially in dry regions and in the case of the marly and "nummulite shale" facies, to yield a rubble of almost perfect nummulite disks which become distributed through the adjacent alluvium and, owing to their wafer or buttonlike shape, are readily transported, both by water and wind, for considerable distances without much wear.

The combined evidence clearly establishes an erosional unconformity between the Nummulitic and the Murree, although it does not appear that within the immediate region under discussion the uplift of the former coincident with the withdrawal of the sea brought about severe deformation. The Nummulitic strata are actually truncated in places by the overlying series, and the latter lies on different horizons of the former at different places, but the angle of discordance in dip is slight and in general not readily noticeable.

SIWALIK SERIES

General statement.—Set off somewhat arbitrarily from the lower portion of the Nimadric system, as above described, the Siwalik is itself conveniently divisible into several lithologic stages. These divisions, viewed as a whole, have distinctions sufficiently constant to enable them to be traced throughout the northwestern Punjab and, at least in this region, represent periods of slightly varied conditions of sedimentation, but they are hardly to be considered as distinctly separable stratigraphic units. Each stage appears to grade conformably into the next, and, owing to the transitional zone, 200 to 500 feet thick, that usually occurs between any two, as well as to lateral changes in lithology, the dividing lines are not precise nor always recognizable at exactly the same horizon. The main divisions are commonly described as the Lower, Middle, and Upper Siwalik, the former being divided into two characteristic portions, termed the Kamlial and Chinji. The outstanding features of these will be described, beginning with the lowest.

Kamlial stage.—In the Salt Range the Murree series is represented, if at all, by a much reduced thickness, and along at least part of the range is believed to be absent. In its place, lying with erosional unconformity and basal rubble upon the Eocene, are prominent sandstone strata which are assigned, on both stratigraphic and paleontologic grounds, to the Lower Siwalik. These strata, together with interbedded siltstones in lesser volume, make up a formation about a thousand feet thick which is widespread in the Potwar Plateau region. It was given the name Kamlial by Pinfold in the Khaur oil field and assumed as the lowest member of the Siwalik series. The typical Kamlial consists in the main of resistent, ridge-forming sandstone, the individual beds ranging in thickness up to over 100 feet. Sandstone composes on the average about four-fifths of the formation, the balance being intermediate and less prominent beds of siltstone, which range in thickness from a few inches up to 30 feet and occasionally more. The proportion of sandstone to siltstone is by no means constant, however. For instance, as one traces the formation eastward to and beyond the east end of the Salt Range, the proportion of silt greatly increases. Many of the sandstone beds are "pseudo-conglomeratic" or contain inclusions of that type in varying abundance. As disclosed in the Jhatla well, about 15 per cent of the Kamlial-Murree beds showed such inclusions. The sandstone is chiefly gray and greenish gray, though varying in color to reddish and purplish brown. The siltstone is mainly of maroon, purplish, reddish brown, and greenish shades. A noteworthy feature is that the purplish tinge in both sandstone and siltstone is more characteristic of the lower

portion of the stage, giving it a strong resemblance to the Murree beds. Upward in the Kamlial the color tends to change to a lighter tinge, more like that of the Middle Siwalik.

No recognizable dividing line nor definite basis of division between the Murree and the Siwalik have been established, and it is not unlikely that in places the lower portion of the terrain that lends itself to mapping as Kamlial actually represents what is elsewhere called Murree, especially where the terrain is thick. Its thickness is 900 feet, as set off in the Khaur anticline from the underlying variegated siltstone beds, which Pinfold considered to be the representative of the Upper Murree. There is no sign of a stratigraphic break and the separation is made on the basis of lithology, the beds termed Kamlial being a ridge-forming body mainly of sandstone.

In the northern belt of outcrop of this stage, about 10 miles north of Khaur (Chirpar Hills) and extending westward toward the Indus (near Gulial, etcetera) and northeastward to south of Rawalpindi and beyond, a total distance of over 85 miles, the thickness of beds that might be correlated as a whole with the Kamlial on lithologic grounds ranges between 1,000 and 2,000 feet. This may include beds at the base equivalent to those called Murree at Khaur, but part at least of the increase is believed to represent northward thickening of the stage. The other main belt of outcrop forms the southern border of the Siwalik area, running in a general east-west direction for over 120 miles along the Salt Range and its appendages. There the formation has a thickness ranging from about 900 feet upward. Much of the thickening takes place at the base of the terrain and probably represents beds called Murree in the north. The varying thicknesses of this Kamlial-Murree terrain in the southern belt are approximately as follows: 1,400 feet near the Indus; 1,000 feet near the sharp bend and highest portion of the Salt Range, 30 miles southeast of the Indus, gradually increasing thence eastward to 1,300 feet in the central portion of the range, to 1,550 feet near Kallar Kahar (not including the prominent transition zone of beds at the top, about 500 feet thick, which has been arbitrarily included with the overlying Chinji), and to 2,070 feet on Diljabba Ridge, 25 miles east-northeast from Kallar Kahar. Twelve to 17 miles farther northeastward, on the Bakrala anticlinal ridge, the Kamlial-Murree terrain has a thickness of about 2,000 feet, and here its lowest beds, which are presumably pre-Kamlial in age, contain abundant vertebrate bones. A similar thickness (2,011 feet) was found in the Jhatla well, 10 miles north of the central portion of the Salt Range. On Mount Tilla, 20 miles southwest of the town of Jhelum and 12 miles southward from the Diljabba and Bakrala

sections, the thickness is 1,800 feet; but just to the south of this, on Chambal Ridge, which intervenes within the few miles that separate Mount Tilla from the plains of the Jhelum River, the thickness is only 900 to 1,000 feet.

Most of the northward thickening that is indicated by these figures for the Salt Range region is presumed to indicate the entrance at the base of the section of beds equivalent to those called Murree farther north. On the Bakrala anticline an attempt to make a separation shows a thickness of 1,100 feet that may plausibly be assigned to the so-called Murree on the ground of its purplish color and the predominance of siltstone, and an overlying formation about 900 feet thick of more reddish sandstone and siltstone ascribable to the Kamlial.

Chinji stage.—Toward the top of the Kamlial the proportion of siltstone increases and there succeeds a finer-grained formation ranging in thickness from 1,400 feet in the southern region to about 4,500 feet in the northern. Taken as a whole, this body of beds has a distinctive character, making it the most readily recognizable of all the stages of the system. It was named by Pilgrim the "Chinji" from a village at the edge of the belt of low relief which these beds form for over a hundred miles along the northern foot of the Salt Range. The same formation is equally extensive in outcrop through the northern portion of the Potwar Plateau. It is composed mainly of siltstone having a warm orange-brown color, regularly banded with lesser beds of ash-gray sandstone. The banding produced by these contrasting colors gives a picturesque effect to the landscape. Of this deposit as a whole the siltstone composes on the average about 70 per cent in the southern belt and a lesser, though still predominant, proportion in the northern one. The siltstone beds vary in thickness up to 200 feet or more, although generally only a small part of that. The sandstone layers rarely obtain a fifty-foot thickness and are usually measurable in terms of only a few feet. The color of the siltstone varies in depth of orange shade, and also to yellowish, brownish, brick red, and purplish hues, whereas the sandstone often assumes an olive and occasionally a purplish color. Lenses of "pseudo-conglomerate" are scattered through the Chinji and occur particularly in its basal portion, but are generally thinner and less abundant than in the more dominantly sandy parts of the system.

The Chinji gives unmistakable evidence of thinning progressively southward. In the northern belt of outcrop, parallel to that described for the Kamlial, its thickness ranges between 4,000 and 4,500 feet. A few miles south of this belt, on the south flank of the Khaur dome, its thickness is approximately 3,500 feet. As revealed in the Jhatla well,

30 miles farther southward, it is 2,800 feet, and 8 miles southward of this, in the type section at the north foot of the Salt Range, the thickness is 2,400 feet. Following the outcrop westward along the latter belt, the Chinji thins to about 1,500 feet near the Indus end of the Range. Eastward from the type section it maintains a fairly even thickness for some miles, but then thins to 2,100 feet on Bakrala Ridge, 60 to 70 miles northeastward from Chinji village. A dozen miles southward from Bakrala Ridge it ranges between 1,550 and 1,900 feet on Mount Tilla, and farther southward attains apparently only 1,370 feet on Chambal Ridge, although at the latter place the thickness may be considerably more, depending on where one draws the upper line.

Middle Siwalik.—The Chinji is fairly sharply overlain by massive gray and grayish buff sandstone, some beds of which have a thickness of 200 to 300 feet. Such sandstone, alternating with usually thinner beds of brownish, tile-red, buff, and yellowish siltstone, continues several thousand feet upward in beds and zones of varying thickness to form the middle division of the Siwalik. In the regions of its best development this division attains a thickness of five to six thousand feet, but it is subject to great lateral variation, both in lithology and thickness. Masses of "pseudo-conglomerate" are characteristic. Sandstone forms the great bulk of this division in the western portion of the Potwar Plateau, but northeastward the siltstone members take the place of much of the sandstone and toward Rawalpindi make up about half of the total volume. Concurrently the siltstone beds, as they increase in thickness, assume a deeper tone of reddish brown. A similar reduction of the sandy phase and increase of the volume of silts is noted to the southward, but as a whole the group is characterized by its thick sandstone zones. Gray is the dominant color of the sandstone, but this varies from light to dark gray, and to greenish and brown shades.

Owing to the lithologic variation and the difficulty of recognizing a consistent line of separation between the Middle and Upper Siwalik, it is impossible to give reliable figures as to the comparative thicknesses of these divisions in different areas. For instance, in the north central portion of the Potwar the Middle Siwalik comprises mainly sandstone from 5,000 feet thick (Dhulian anticline, between Pindi Cheb and Soan River) to 6,000 feet (Ahmdal syncline, north of Khaur), whereas a decided thinning of this sandstone mass takes place both to the west and east and also to the south. Forty miles westward from Khaur, on the north flank of the faulted Dakhnir anticline near the Indus, the thickness of the beds, which were mapped as Middle Siwalik, is about 3,500 feet, and a similar distance eastward from Khaur the thickness is not much

over 2,000 feet; but with this thinning there appears to go a thickening of beds resembling the Upper Siwalik. In the southern portion of the Potwar—that is, south of the Soan synclinal basin—the Middle Siwalik is represented by from 2,000 to 3,000 feet of predominantly sandstone beds overlain by thicknesses varying up to as much again of mingled siltstone and sandstone which might be ascribed to either Middle or Upper Siwalik.

Upper Siwalik.—The Upper Siwalik is distinguished by the very greatly increased volume of conglomerate and coarse sand, as compared with the older parts of the system. Locally a line of separation between the Middle and Upper Siwalik divisions can be based on the entrance of thick deposits of conglomerate, representing the commencement of a more torrential type of deposition. Elsewhere, however, there is perfect gradation. Conglomerates also occur in the Middle Siwalik and suggest that the transformation in the conditions of sedimentation was a progressive and not a sudden one. The Upper Siwalik, as a whole, is the most variable division of the Nimadric system. It is not unusual to find thick zones of siltstone or sandstone which locally might be taken to have almost formational importance changing laterally into coarse conglomerate, or *vice versa*.

Aside from the conglomerate, which forms a considerable, though still subordinate, part of this division, the Upper Siwalik is composed largely of whitish gray and brownish sandstone and semiconsolidated sand and siltstone beds of varying shades. Among these shades are straw and mustard colors, faint lavender, greenish gray, buff, orange, and even deep tile red. On the whole, however, this division is lighter-colored than lower parts of the system and less bright and variegated than the enumeration of these colors might suggest. Some individual conglomerate lenses are as much as 250 feet thick. The inclusions are well water-worn pebbles, cobbles, and boulders of metamorphic, igneous, and other rocks, including Nummulitic limestone. The boulders do not usually exceed a diameter of 10 inches. The Upper Siwalik forms the surface of approximately half the Potwar Plateau, occupying the synclinal basins and being absent, almost certainly owing to erosional removal, on the summits of all the anticlinal domes.

The thickness gradations of the Upper Siwalik are difficult to estimate, owing to its higher portions being locally worn away or hidden and owing also to its changing facies and the doubtful correlation from region to region of the line of separation from the Middle Siwalik.

The beds mapped as Upper Siwalik have the following approximate thicknesses in various districts: Near the Indus, in the northwestern

part of the Potwar, 5,500 feet; in the center of the Soan syncline, in the western part of the Potwar, 4,500 feet (but probably not all present); in the Soan syncline, south of Khairi Murat Ridge (southwest of Rawalpindi), over 6,000 feet (but probably including some Middle Siwalik); and in the Jhelum district, to the southeast, 1,500 to over 4,000 feet, depending on where the base is placed. A more correct idea is conveyed by combined thicknesses of Middle and Upper Siwalik beds exposed in single sections, some of which are roughly as follows: Northwestern part of the Potwar (Dakhnir anticline), 9,000 feet; northeastern part of the Potwar (south of Khairi Murat Ridge), 8,500 feet; Bhaun syncline, in south central part of the Potwar, 4,650 feet, with only 1,500 feet (probably lower part) of Upper Siwalik present; region of Bakrala Ridge, about 25 miles northwest of Jhelum, 8,000 feet; region of Chambal Ridge and Kharian anticline, south of Jhelum and at edge of the plains, 5,500 feet.

STRUCTURE

GENERAL STATEMENT

The Potwar Plateau is, broadly speaking, a geosyncline between the Salt Range on the south and the front ridges of the Himalaya on the north. By the latter ridges are meant the mountain outliers and hills which form a southwardly convex arc extending from Muzaffarabad, on the Jhelum, and from the hill station of Murree southwestwardly to the Indus some miles downstream from Attock. This arc and the similar ones farther north are included with the Himalaya Range, although, as pointed out by several writers, their trend allies them to the Hindu Kush Range and sets them off from the southeastward-trending structures of the main Himalayan arc east of the Jhelum.

The structural axes in the Potwar region run generally parallel with the ranges to the north, usually along east-northeast and west-southwest lines. The parallelism of the Salt Range with the northern arcs is striking, but as would be expected in a wedgelike segment such as this region is, between the northwest-southeast arc of the Himalaya east of the Jhelum and the north-south lineaments of the Suleiman ranges west of the Indus, the structures here, and particularly at the ends of the Salt Range, show the effect of compression from the sides. These various features are displayed in the topography, and the recency of deformational movements is reflected in anticlinal and fault ridges and synclinal basins.

Along the northern belt the strata are highly compressed and faulted, the dominant feature of the structure being overfolding and overthrusting from the north. The belt contains in closely packed space a concen-

tration of broken segments resulting from foreshortening. The series there are Murree, Nummulitic, and older. Southward the structures become more simple and moderate, so that the central and southern portions of the Potwar Plateau, as well as the Salt Range, contain wide areas of gentle dip and several broad folds. The Siwalik beds cover the major portion of the central and southern area. The southeastern portion of the region, within a radius of 30 miles or so of Jhelum, is an exception to the comparatively gentle structure just mentioned. This district contains several compressed and southward thrust anticlines that form ridges extending northeastward from the Salt Range. The latter range itself is a northward-dipping monocline or the north flank of an original broad anticline which has been overthrust to the southward. Evidence of the overthrusting is mentioned in the discussion of the Eocene system early in this paper. The overthrust mass, and particularly its southern face, has broken down in numerous places by normal faulting, such collapse being doubtless aided by solution in the salt and gypsum beds that form the basement. The scarps facing the plains to the south expose above the Eocene "salt marls" a two to three thousand foot section of moderately tilted strata ranging upward from early Paleozoic to Eocene. On the other hand, the crest and northern side of the range is formed mainly by the Nummulitic limestone and Lower Siwalik sandstones, which dip northward beneath the Potwar geosyncline.

It is to be noted that the area now occupied by the Potwar and regions of unknown extent to the north within the present Himalayan province (as well as to the south during the Siwalik epoch) formed part of the submontane depression in which the Nimadric system was accumulated. The present geosyncline of the Potwar Plateau represents only a foreshortened portion of the original plains.

The depth of the top of the Nummulitic in the deepest parts of the present geosyncline is seventeen to twenty thousand feet below sealevel, on a conservative estimate of the thicknesses involved, and nearly 2,000 feet more below the present level of the country. Thus, if we consider the rim of the basin as being at the general level of the lower outcrops of the Nummulitic on the sides, we get a figure on the order of 20,000 feet or more as the present depth of the saucer filled by the Nimadric system. Actually the Murree beds rise to over 7,000 feet in the Himalayan front range near Murree, and the Nummulitic limestone forms heights still more elevated. These figures convey an idea of the scale on which dislocation of the crust has gone on and the scale of deformation represented by the vast thickness of Nimadric deposits.

STRUCTURAL ZONES

Dr. MacKay's summary.—Dr. B. R. MacKay, in a report submitted in 1922, gives the following summary of the structural features of the region, partly following Pinfold's description:

Based on the prevailing types of structures present, the region may be divided into a number of structural zones. From north to south, these are: (1) the isoclinal zone, (2) the fault zone, (3) the anticlinal zone, (4) the Soan synclinorium, (5) the terrace zone, (6) the Salt Range monoclinal zone, and 7) the Salt Range anticlinorium.

The zones are exceptionally well developed in the central part of the region, between longitude 72° 00″ and 72° 45′. Most of the region lying between the Soan synclinorium and the Jhelum River to the southeast may be considered as constituting a separate fault zone, whereas the terrace zone of the western part of the district gradually merges eastward into a separate anticlinal zone.

Isoclinal zone.—In the northern part of the area, along the Margala and Kala Chitta ranges, the rocks are so intensely squeezed, crushed, faulted, and overturned that in many parts it is impossible to represent the structure correctly on a map of a scale of 1 inch to 1 mile. This belt of greatly disturbed strata extends from the Jhelum to the Indus River and has a width of about 20 miles. It is bounded on the south by a marked strike thrust-fault, which crosses the Indus near Jand and which is traceable eastward from the Indus for a distance of over 40 miles, passing to the south of the Khairi Murat Range. Over most of this area the folds are not only overturned southward, but are so tightly squeezed that nothing remains of their crests, and both limbs lie in contact, so that they can be distinguished only by the most careful scrutiny.

Fault zones.—To the south of this fault the folds are much more open and the rock succession is easily elucidated. For a distance of 12 miles immediately south of the fault, in the vicinity of the Indus River, the rocks are arranged into a series of open synclines separated either by strike-faults or closely folded anticlines. On most of these synclines the axial planes dip to the north. The synclines are closely packed together and generally separated from one another by narrow saddles. At least four prominent strike-faults occur within this zone, all of which dip to the north. This fault zone is limited on the south by a prominent fault which crosses the Indus near Malangi, 16 miles south of Khushalgarh, and extends eastward for a distance of over 15 miles. This fault lies along the crest of the Dakhnir anticline and apparently plays out on the south flank of the Kharpa fold.

Between the Soan River and Jhelum occurs a zone, over 40 miles in width, characterized by a series of broad, open synclines, separated from one another by long, narrow, tightly squeezed and in places overturned anticlinal structures. Strike-faulting is generally pronounced along the axis of the anticlines, and the shortening that has taken place is indicated by the lost intervals which occur on the northern flanks of the synclines and the southern limbs of the anticlines.

Anticlinal zones.—Lying south of the Malangi boundary fault, there occurs a belt, about 12 miles in width, extending from the seventy-second meridian eastward to meridian 72° 45′, which is characterized by a large anticlinal fold with the Dhulian and Khaur domes as the crestal areas. This zone has been aptly termed by Pinfold the "anticlinal zone."

Another section of the district characterized by the development of prominent anticlinal structures stretches north-eastward from the eastern end of the Jhatla dome for a distance of about 40 miles, where it passes into the fault zone of the eastern district. In the vicinity of the Jhatla dome this zone has a width of about 8 miles, and gradually increases eastward until it attains a width of over 12 miles.

Soan synclinorium.—The central zone of the Rawalpindi (or Potwar) Plateau is characterized by a broad synclinorium, which extends from Murree southwestward and westward to beyond the Indus River. In the central part of the district the synclinorium has a width of about 15 miles, while near the Indus the width increases to approximately 25 miles. The shallowest part of the synclinorium lies between the Dhulian and the Jhatla domes, while to the northeast and to the west of this there occur conspicuous basins, 2,500 to 3,000 feet deeper. The axis of the synclinorium parallels and lies a little south of the Soan River, from which stream it derives its name.

Terrace zone.—In the central and western part of the district the southern flank of the Soan syncline rises gently and flattens off to form a broad terrace belt which extends from the Indus River eastward to beyond the Jhatla dome. This terrace is especially well developed in the region northeast of the Jaba seepages and in the vicinity of the Jhatla dome.

Salt Range monocline.—The Salt Range monocline constitutes a belt 4 to 10 miles in width of northeastward and northward dipping strata along the northern flank of the Salt Range. The dips of the strata over this zone vary from 5 to 60 degrees, exposing in certain sections a thickness of over 4,000 feet of Siwalik sediments. To the east of the Jhatla dome the monocline is not so well defined as in the western Salt Range, owing to the intense faulting and crushing which characterize this part

of the district, but it may be considered as conforming with the northward slope of the main Salt Range eastward as far as Chambal Ridge.

Salt Range anticlinorium.—The Rawalpindi Plateau is terminated on the south by the Salt Range, a broad anticlinorium on which are developed a number of minor folds. The structure is characterized by very gentle dips on the northward slope and much steeper dips on the southern flank, where remnants of this flank remain. Throughout most of its length no evidence of the southern limb of the anticlinorium is to be found, and it is believed that this flank has been overridden by the northern flank, as a result of an overthrust from the north. From the Indus River eastward to beyond the seventy-third meridian the Salt Range forms a single anticlinal structure, but to the east of the seventy-third meridian it breaks up into three prominent spurs, the Bakrala anticline, the Mount Tilla anticline, and the Kharian anticline, with a number of subsidiary folds.

Range and Source of Petroleum

It is not within the scope of this paper to describe the numerous seepages and other evidences of petroleum, but they may be briefly summarized as occurring primarily in the Nummulitic series, and mainly, though not wholly, in its upper division, where their best manifestations as seepages are in fine-grained sandstone beds. Secondarily, they occur in such beds of the Nimadric system as lie in favorable structural positions on the Nummulitic. Locally the petroleum has risen through many hundreds of feet of the basal Nimadric beds, this being most markedly the case in the sharply anticlinal and moderately faulted Khaur oil field, where it has collected through more than 2,000 feet of these beds. No strata have been found in the Nimadric which could be considered a source for the oil, and the evidence all points to the highly foraminiferal and otherwise fossiliferous deposits of the Eocene as the original source.

Tertiary History

General statement

An attempt will here be made to interpret briefly what must have been the conditions during the post-Eocene period, in view of the character, distribution, and structure of the Tertiary strata in this portion of India.

Conditions represented by the Nimadric system

Subaerial deposition.—The greater part of the Nimadric strata were, with little doubt, accumulated subaerially through the agency of streams,

aided by the wind. The deposits are of a fluviatile type, with the admixture of much material that might be windborne. The fairly well stratified, although cross-bedded and lenticular beds, the relatively homogeneous zones traceable over wide stretches of country, and the fine-grained silty and sandy nature of most of the system represent sedimentation on broad plains, over which rivers of considerable size and low gradient meandered. There probably were local and temporary lake and marsh accumulations, though such have not been definitely recognized in the strata themselves. The remains of diving birds of the pelican group bear testimony to the presence at times of considerable bodies of water. The bones of such animals as crocodile, hippopotamus, turtle, etcetera, suggest floodplain streams, in harmony with the evidence of the sediments.

Balanced uplift and subsidence.—The vast thickness of the system and its relative similarity throughout leave no room for doubt that there was a long-continued process of gradual subsidence of the basin in which it was laid down—a subsidence that kept approximate pace with the rate at which sediments were supplied and were spread over the plains. Until the close of the Middle Siwalik, the highlands which furnished these sediments must have been at a considerable distance from the area which received the deposits now preserved. The coarser submontane phases which doubtless existed originally must have been far within the district now occupied by the mountains, where they have been worn away. Temporary or local interruptions, or even reversals of the process, may have taken place, and it is fairly certain from the changing facies of different parts of the system, as previously described, that at least the rate of the processes was variable. Presumably, for instance, the dominantly sandy formations in the Murree, Kamlial, Middle Siwalik, and, above all, the conglomerates of the Upper Siwalik denote rejuvenation of the mountains and streams; but, viewed in the large, the system is the record of a continuing major process of concurrent subsidence and aggradation of the plains, combined with uplift and erosion of the tributary mountain areas. These activities served to balance each other in a remarkable way, so as to preserve the equilibrium of a fairly constant surface elevation and conformation of the plains and a constant source of sedimentary material. The system affords a magnificent demonstration of the coordination of these joint processes.

Similar sedimentation today.—The conditions of sedimentation may be fairly closely pictured by comparison with those prevailing today over the plain of the Ganges and the Indus, which, judging by its low elevation above the sea and the thickness in places of its alluvial fill, is in part

undergoing subsidence and aggradation in continuance of the processes prevailing earlier. The relation and position of mountains, plains, and sea during the Nimadric period were probably very similar to those of the present, except that in the earlier part of the period arms of the sea approached on the southwest nearer than today and penetrated deeply the present continental area in the Assam region on the east.

Climate.—Climatically, also, the conditions were presumably comparable with those of the present, with seasonal winds from the ocean on the south bringing moisture and precipitating it on the plains and on the southward-facing slopes of the encircling mountains; but the climate in the Punjab region would appear to have been less arid than now and more similar to that of portions of India somewhat farther east. The remains found throughout the Siwalik series of an extraordinarily rich and varied fauna of herbivorous animals bear witness to the existence during that epoch of vegetation and moisture in excess of that of the Punjab today. They also help to confirm the picture, deduced from the sediments themselves, of wide-spreading floodplains on which these animals found pasture.

Pieces of tree trunks, lignite laminæ, and poorly preserved palm and other plant remains scattered through the system are in accord with this conclusion, although leaves and stems are not as abundant as might, perhaps, be expected. The occurrence in the Siwalik of petrified logs, and also the bones of primates, which presumably were arboreal forms, show that the region was at least locally wooded. The scarcity of soluble salts in the beds, as indicated, for instance, by the freshness of the underground waters obtained in the deep Jhatla well, is a further evidence that the region was not arid.

On the other hand, there is support for the belief that the climate was intermediate between the semiarid condition now prevailing in western India and the tropical jungle type of eastern India. The preservation of the bones in such abundance suggests a certain degree of dryness, especially as many of them show the effect of long exposure to weathering before being buried. The "pseudo-conglomerate" deposits and the absence, so far as the writer has observed, of old soil deposits also convey a similar impression. The reddish colors characteristic of many of the strata throughout the system, and present at depth in wells just as in surface exposures, probably indicate that such beds were subject to seasonal or occasional drying; and the presence of animals ancestral to the modern giraffe, camel, and ostrich appears in harmony with the idea of moderate precipitation. The mingling of these animals with the numerous species of elephants, with horses, oxen, antelopes, rhinoceros, lizards, and other

forms, including their carnivorous associates, bears out the conception of a locally forested and locally open country of low relief, under a semitropical climate of medium rainfall. Judging from the profusion and variety of the fauna and its continuity of development through long periods, the life conditions must have been unusually favorable, as well as comparatively stable.

These deductions as to climate apply mainly to the Siwalik portion of the period, inasmuch as beds definitely known to be Murree have not yet yielded good remains of a fauna except from the lowermost zone. In such a long period it would be rash to imply that changes did not take place; but the above conditions are those indicated to have been predominant, and such data as we have from the Murree beds (palm and other plant remains, similarity of sediments to those of the Siwalik, vertebrate fauna in the basal zone and in other beds believed to be Murree) support a presumption in favor of similar conditions during the Murree epoch. It is to be noted that the moderately rainy climate of the Nimadric period contrasts with the aridity which must have prevailed in the epoch represented by the saline deposits of the Nummulitic. The formation of the ancestral Himalayan Range was probably the chief factor in this transformation, providing a barrier in the path of moist winds from the south.

Orogenic sequence.—At the close of the marine period of the Eocene there was uplift of continental proportions which elevated a vast area above sealevel. This was evidently not merely linear deformation, creating one or more mountain ranges, but rather a fairly uniform uplifting of the former marine basin to above sealevel without strong deformation in the region here discussed. Coincident with or following on this movement, however, there were presumably reawakened deep-seated zones of shear which became projected to the surface in the form of flexures in the blanket of Eocene deposits, thus creating local highlands. Such a mountain area must have been within the present Himalayan province, but far to the northward of the front ridges of today. An ancestral Salt Range was also one of these uplands, as shown by the almost complete removal of the upper stage of the Nummulitic from the top limb of the range, by the entire or approximate absence there of the Murree series, and by the coarse fragments of Nummulitic limestone inclosed in the basal beds of the continental system as laid down there. In the Salt Range area the great Paleozoic and Mesozoic succession of strata had been previously little disturbed, but there is evidence in old unconformities that the post-Eocene flexing took place along an ancient zone of warping.

With uplift of the Nummulitic series erosion affected particularly the more elevated tracts just mentioned, thus bringing about during an epoch intervening between that of the Nummulitic and that of the oldest Nimadric beds so far recognized the eroded surface of gently uptilted Eocene and locally older strata on which the Nimadric of this region was deposited.

Judging by the mass and character of the Nimadric sediments, the grains of which resemble the Himalayan rock types, by the thinning of the members southward, and by evidence that deformation and erosion both prior and subsequent to the Eocene has progressed much farther in the mountain province than elsewhere in this general region, it may be assumed with assurance that the ancestral Himalayan Range was the chief source of the materials. The continuing process which gave rise to these deposits is inferred to be as outlined in the following paragraphs.

Uplift in the Himalayan province constantly progressed by means of compressional forces first folding and then upthrusting the strata of that range. Such thrusting in this immediate region was southward or south-southeastward along numerous more or less east-west lines. As the rocks of the mountains, including the Eocene strata, were pushed upward and southward, the plains region to the south received the products of erosion and concurrently subsided. It would seem that such subsidence might readily be due in part to overweighting by the encroaching mountain mass as well as to the loading on it of sediments. Downwarping of the lower limbs of overturned frontal folds also doubtless played a part. The depression of the plains segment may best be interpreted as a downward tilting of the northern fringe of the land on the south with the greatest amount of subsidence near the foot of the Himalaya, as indicated by the declining thicknesses of the Nimadric deposits southward. For a time the general zone of the ancestral Salt Range would appear to have formed the southern boundary or hinge of the sinking area, because the evidence goes to show that it was the southern limit of deposition of the Murree beds. Later, the Salt Range area subsided with the rest and was buried beneath several thousand feet of the Siwalik sediments. During this later period the southern edge of the depressed area was much farther to the south, as indicated by the normal succession of Siwalik deposits in the Salt Range monocline and around the eastern end of the range. The possibility suggests itself that the northward-dipping ancient strata reported seventy-five years ago by Fleming in the isolated Korana Hills, which rise out of the plains some fifty miles south of the Salt Range, represent deformation, perhaps southward thrusting, along the southern hinge of this Siwalik downtilting or downwarping.

As the processes above mentioned progressed it is to be inferred that a southward transgression or growth of the Himalayan Mountain area took place by means of forward movement on many thrust-planes, and as a result of new folds and thrusts that developed in the belt of previously little-disturbed Eocene, and in the Nimadric beds themselves, along the southern border of the mountains. Evidence of this is afforded by the upper (Chharat) division of the Nummulitic and the Murree beds being involved in the severe overfolding of at least the front ridges of the Himalaya, although it remains to be proven that any of the disturbance of the Murree beds, in the structures where they are still preserved, was earlier than late Tertiary. The amount of foreshortening that the Eocene and Nimadric beds have undergone through close folding and overthrusting, as well as through the more open folding of the Potwar, shows that the original plains on which the subaerial system was laid down were far wider in a north-south direction than the present area of outcrop. Other evidence of such southward growth of the range is to be found in the absence along the northern border of the Potwar of the coarse submontane phases of the lower and middle portions of the Nimadric system, which must originally have occupied northward extensions of the basin of deposition. These evidences combined serve to set back to the extent of scores of miles the Himalayan front in the earlier ages of the Nimadric period, and similarly it is certain, from the evidence of overthrusting of the Salt Range, that the ancestor of the latter range was miles to the northward of its present position.

At about the beginning of the time represented by the Upper Siwalik, and the commencement of deposition of gravel and boulder beds, there came the most marked change of which we have record in the conditions of deposition of the system. There was either pronounced uplift of the tributary mountain areas and rejuvenation of the rivers or a forward thrusting of the mountains to bring them closer to the area of deposition. The evidence indicates a combination of these causes. To supply the coarse conglomerates which we find, the mountains must have been both high and close. Another factor which very likely had a part, but which could not have been sufficient alone to account for the coarse deposits of the Upper Siwalik, was increased seasonal precipitation, with the consequent increased transporting power of streams. It is to be noted that a somewhat greater concentration of rainfall in the immediate region represented by these deposits would be expected to result from the rise and nearer approach of the mountain front. Indication of such greater precipitation may perhaps be afforded by the decrease in density of coloration by oxidized iron compounds in most of the later Siwalik as compared to the earlier portions of the system.

The inference is drawn that the encroachment of the mountains was not a sudden thing, taking place toward the end of Middle Siwalik time, and again at the end of the whole period, but was a gradual process, going on, with minor interruptions and occasional stimulation, throughout the Nimadric period. Evidence in support of this is to be found in the continual supplying of great amounts of sediment, of fairly constant types, which indicates progressive rejuvenation of the mountains keeping pace with erosion. Southward overfolding and thrusting, being a dominant structural tendency in this region, undoubtedly was one, if not the major, factor in the process of rejuvenation. In addition, the indications of southward transgression of the deposits, without evidence of greater distance from the source of supplies, supports the view that the encroachment of the mountain province was progressive. The great sandy formations in the system presumably indicate the periods of prime activity, whereas the dominantly silty formations, like the Chinji in particular, may be taken to represent periods mainly of quiescence and wearing down of the mountains.

The period ended with deformation affecting the whole system and, for the time being at least, terminating the process of regional subsidence within the Nimadric province. The information so far obtained does not warrant a definite conclusion as to whether the folding and faulting of all the beds of the system in the region where they now outcrop was brought about by severe deformation concentrated at the end of the period or represent a culmination of activity commencing earlier. It is not yet known whether the latest beds of the system were laid down coextensively with those preceding or represent deposition in slightly restricted basins produced by warping. It is possible that the folding of parts of this province began contemporaneously with the activities already mentioned as being indicated by the Upper Siwalik type of sediments; but the Upper Siwalik participates in all the folds, both moderate and severe, being tilted parallel with the earlier strata, and it is clear that most of the folding and faulting of the Potwar and Salt Range region was brought about after the close of the Nimadric period. We must look to the present mountain region farther north for the main locus of deformation indicated as having taken place during earlier portions of the period.

In accordance with the evidence afforded by the structural features of the Upper Siwalik, the present Salt Range is believed to have been chiefly formed subsequent to the Nimadric period. The commencement of its reelevation may, however, date from the time of rejuvenation of the Himalayan Range, already mentioned as represented by the Upper

Siwalik gravels. There is evidence in these coarse gravels themselves, as now exposed around the Salt Range, that their source was near.

Proof is lacking as to whether all of the Siwalik series was laid down on the Salt Range area, but the indications are that the whole series was deposited there, being later removed in large part by erosion. The Kamlial beds still cover considerable areas on the range, whereas the later divisions of the Siwalik outcrop regularly on the north flank and around the eastern end of the range. All divisions of the Siwalik take part and have great thickness in the sharp anticlinal and faulted offshoots of the range in the Jhelum District, like the Kharian, Rhotas, and Bakrala anticlines, which are undoubtedly post-Upper Siwalik in age. There is no evident reason for doubting that the Salt Range was in the main contemporaneous with these. The uplifting of the range must have been a long-continued process, however, involving first warping and then gradual overthrusting on the "salt marls." Moreover, there is evidence that some folding and faulting has taken place subsequent to the main thrusting. The consistent occurrence of the saline and gypseous formation beneath the overthrust along the foot of the range for a hundred miles or more is a remarkable feature. These deposits would provide a lubricating medium for the thrust, and it is probable that their presence as the basement is not to be explained by erosional uncovering during a hypothetical long epoch intervening between the late or post-Siwalik upwarping and the faulting, but rather by bed-thrusting on a gigantic scale. In any case, the conclusion may be drawn with a fair degree of assurance that the upper limb or main mass of the range, as we now see it, was raised at the end of the Nimadric period and subsequently—that is, largely during the Quaternary.

Appendix: Record of the Jhatla Well

Location, structure and objective

Beginning in February, 1923, the Whitehall Petroleum Corporation, Limited, drilled the deep well before mentioned, north of the Salt Range. Its location was in the Gandial Ravine, 2¼ miles west-northwest of the village of Jhatla, 8 miles southwest of Talagang, and about 24 miles westward from Bhaun, the termination of the Mandra Branch Railway. The elevation of the surface at the well is 1,740 feet above sealevel. It was drilled on the summit of a broad anticline separated by the deep synclinal basin of the Soan River from the sharp anticline of the Khaur oil field, 30 miles to the north. The purpose of the well was to determine whether oil accumulations occurred here in the Nimadric system,

as they do in the Khaur field, and its final objective was the base of that system and the top of the Nummulitic. It was completed, at a depth of 6,007 feet, in April, 1925, without obtaining more than traces of oil. The Nummulitic limestone was reached at 5,925 feet.

DRILLING METHODS AND CASING

The well was drilled with a combination cable and rotary rig to a depth of 4,401 feet, and from there on with a Sullivan diamond drill to a final depth of 6,007 feet. It was drilled with cable tools to 560 feet; thence by rotary to 775 feet; thence by cable to 1,328 feet; rotary to 3,711; cable to 3,756; rotary to 4,393, and lastly by cable to 4,401, prior to installing the diamond drill. Various sizes of casing were carried to the following depths: Twenty-inch casing was set at a depth of 514 feet; 15½-inch casing at 1,075 feet; 12½-inch set and cemented at 1,953 feet; 10-inch set and cemented at 2,894 feet; 8¼-inch set at 3,841 feet; 6¼-inch set and cemented at 4,400 feet; and 5⅛-inch set at 5,308 feet. The diameter of the hole at the bottom was four inches.

Deflection tests showed the well to be practically vertical at the depths tested, and there was no indication that it was not close to vertical throughout. Similar evidence was afforded by the horizontal stratification of the beds in the cores. The tests, considered accurate to within one or two degrees, gave a deflection of 1.5 degrees at a depth of 5,485 feet; the same at 5,645 feet, and 1 degree at 5,805 feet.

STRATIGRAPHY OF THE WELL

The Jhatla anticline is a broad dome in the Middle Siwalik beds, covering an area of over 30 square miles, and elongated in an east-northeast direction. On the crest the strata are virtually horizontal, but a dip of about two degrees is attained within a third of a mile, both to the north and to the south of the axis. Farther away the strata on the north flank increase in dip to about ten degrees and on the south to about three degrees. The well started at a horizon estimated by surface measurements in the vicinity to be approximately 1,100 feet above the base of the Middle Siwalik. The depth to the top of the Nummulitic was estimated to be between 5,000 and 6,100 feet, and a point between 5,600 and 6,100 feet was considered the most probable figure. In making this estimate the chief factor of uncertainty was not the thickness measurements of the formations exposed at the surface, but the problematical extent to which thickening and introduction of older beds of the Nimadric system might take place northward from the exposed section on the north flank of the Salt Range. Based on the thicknesses in the

nearest sections to the south, the depth to the Nummulitic would be only 4,700 feet (lower part of the Middle Siwalik, 1,100 feet; Chinji, including transitional zone at base, 2,400 feet; Kamlial, 1,200 feet); but the Siwalik series increases in thickness northward toward the Himalayas, and, moreover, the Murree series, absent or thin in the outcrop along the Salt Range, was bound to enter in and also increase in thickness northward. Accordingly, the assumption was made that there would be a gradual thickening, roughly proportionate to the distance and the difference in thickness between the outcrops on the south and the next sections to the north, near the Khaur oil field, about 40 miles north of the Salt Range. The estimate considered most likely was as follows: Lower part of Middle Siwalik, 1,100 feet; Chinji beds, 2,890 feet; Kamlial-Murree, 1,700 to 2,080 feet, making the total depth from 5,690 to 6,060 feet.

The result of the well proved these measurements and assumptions to be close to the truth. The base of the Nimadric and top of the Nummulitic were reached in the well at a depth of 5,925 feet. No precise lines of separation exist between the various Nimadric stages, any more than they do on the surface, but the major divisions were well characterized and the dividing lines are taken to be as follows, on the basis of the general character of the beds as well as the examination of heavy residues: Base of Middle Siwalik at about 1,107 feet; base of Chinji at about 3,914 feet, the beds to here from about 3,636 feet being of the type transitional between Chinji and Kamlial; base of Kamlial-Murree, 5,925 feet. On the basis of this interpretation the Chinji in the well has a thickness of 2,807 feet, of which the lower 278 feet are transitional; and the combined Kamlial-Murree, between which no line can be drawn, is 2,011 feet thick. In addition, the well penetrated 82 feet deeper through the Eocene beds to a final depth of 6,007 feet.

In a boring of such depth it is interesting to note that the strata conformed in color, hardness, porosity, and other features, as well as in thickness, to the conditions observable in fresh exposures at the surface; also, in structure there was no sign of displacement of beds from their normal position and approximate horizontality. A slight progressive hardening was noted downward in the section, with increase in evidences of induration, such as small calcite veins and calcareous cementation, but these features may also be noted in surface sections, the tendency being for induration to increase gradually the older the beds are in the Nimadric system.

FOSSILS IN THE EOCENE

Samples from the depth of 5,925 down to the bottom of the well were submitted to Dr. W. L. F. Nuttall, at Cambridge University, for examination of the fossils. He kindly made slides and reported as follows:

"The Foraminifera identified are small radiate *Nummulites* and *Dictyoconoides* cf. *conditi*, which indicate that these beds are of Eocene age. Ostracods as well as pelecypod and echinoderm fragments are also present. I am afraid that the fauna is too poor to venture an opinion whether the age of the limestone is Middle or Lower Eocene."

DESCRIPTION OF STRATA IN THE LOG

During the drilling (except for the first 300 feet) a geologist was constantly at hand to obtain and study samples of the material penetrated. The log was kept by Mr. W. F. Eastman down to a depth of 5,311 feet, and from there on by Mr. D. Dale Condit. The geologic section is, therefore, much more accurate than the ordinary "driller's log," but it must be born in mind that such a log at best has limitations, owing to the conditions of sampling. Below the depth of 4,401 feet, where coring with the diamond drill commenced, it is nearly exact, the core brought up intact aggregating over four-fifths of the depth drilled from there down, and the intervals of broken and lost core being subject to close interpretation. For the upper 4,400 feet, drilled with rotary and cable tools, chiefly rotary, the element of interpretation enters in to a greater degree and the detail of beds can not be so closely described. Generally speaking, through this upper 4,400 feet it was difficult to distinguish thin beds of sandstone or siltstone as separate entities and difficult to estimate precisely the proportion of fine and coarser sediment represented in a zone when the two alternate in thin layers or are mingled. It is believed that a bed of siltstone as much as four feet thick never failed to be recognized, but sandstone beds, unless somewhat thicker than that, were apt to be obscured in the rotary drilling, except when revealed by a change in hardness from the adjoining layers. However, in a relatively thick-bedded series such as we are dealing with, the log records the alternation of coarse and fine sediment with fairly close detail.

Certain explanations are desirable as to the descriptions given in the subjoined log. In accordance with the usage adopted in this paper, the term "siltstone" (abbreviated to sls.) is used instead of "clay" and "shale," inasmuch as it was found impossible to employ either of the latter terms truthfully or both of them with any consistent distinction. Similarly, the adjective "silty" is applied to some sandstone beds with

respect to which the description "clayey" or "shaly" might with a certain amount of truth be applied. It denotes not so much fineness of the whole bed as an admixture of fine silt in the form of a matrix, or in lenses or layers, giving the bed a claylike toughness or occasionally an approach to shaly structure.

As regards color of the beds, the predominant color of the sandstone is gray, and where no color is mentioned an assumption of gray will be correct in the great majority of cases. In the case of the siltstone beds, they may be assumed to be of the shade of tile red characteristic of the associated siltstones in the particular part of the column where they occur. Beds of mingled sand and silt or of intermediate size of grain usually have an intermediate color, a paler shade than the fine siltstone. The term "reddish brown" denotes the dull reddish brown or tile color characteristic of the siltstone beds in the Middle Siwalik and of some of those in the Kamlial. The terms "red" or "reddish," where used in the log without qualifying adjective, denote the color characteristic of the Chinji siltstone, a tile red with an admixture of pinkish and yellow which gives it an orange hue and bright aspect. This color also occurs occasionally (both in the field and in the well) in the Middle Siwalik and the Kamlial.

The beds are notable for their usual lack of coarse material. The terms fine, medium, and coarse are used as comparative terms with relation to the usual texture of the sandstone of the system itself. Of the sandstone designated "coarse" the major portion of the grains would range between one-half and 1 millimeter in diameter, with a minority of grains ranging up to 1½ and 2 millimeters. It is noteworthy that no really coarse sandstone, nor conglomerate of pebbles extraneous to the Nimadric system, was detected in the well, except the basal rubble overlying the Nummulitic.

Calcareous cement is present throughout, and all samples tested gave a strong effervescence in hydrochloric acid. Porosity tests made by D. Dale Condit of core samples of the Kamlial-Murree sandstones, and numerous tests of the same which were kindly made by Mr. A. F. Melcher, showed a porosity range of from 8 to 17.5 per cent by volume in the "fine" to "medium coarse" grained sandstones. The density of the specimens examined ranged from 2.68 to 2.71, with an average of 2.69. Samples of fresh sandstones taken from outcrops of the Murree and Siwalik showed approximately similar porosities, with a tendency to increased porosity where the calcareous cement had been leached out.

TEMPERATURES IN THE WELL

On the basis of the data mentioned below, the temperature at the bottom of the Jhatla well, at the depth of 6,007 feet, or 4,267 feet below sealevel, was approximately 172 degrees Fahrenheit. This gives a temperature gradient of one degree for each 49⅓ feet, if we assume 50 degrees Fahrenheit as the surface temperature of the ground.

The mud bailed from the bottom of the well when it had reached about 3,740 feet showed a temperature of 110 degrees Fahrenheit when brought to the surface in the bailer. It undoubtedly lost heat on the way up through the well. Assuming such loss as ten degrees, and it was probably more, this would give 120 degrees Fahrenheit as a minimum estimate for that depth. Such temperature would represent a gradient of one degree for each 53 to 54 feet on an assumption of 50 degrees as the surface temperature. A better basis is afforded by temperatures taken with a deep-sea thermometer after completion of the well, but the figures can not be considered as accurately corresponding to the depths because the hole was full of water. The measurements were as follows:

Depth in feet	Temperature in degrees Fahrenheit
2,780	115
3,210	127.4
3,860	134.6
4,380	140
5,820	168.4

The last figure is doubtless nearly correct for that horizon, being only 187 feet above the bottom of the well, but it is believed certain that the figures for the higher levels are excessive, owing to the water in the hole being influenced by the bottom temperatures. The temperature of 168.4 degrees Fahrenheit for 5,820 feet gives a temperature gradient of one degree for each 49 feet, assuming 50 degrees as the surface temperature. It is possible to arrive at a close figure for the temperature at the bottom of the well, at 6,007 feet, by projecting below 5,820 feet the curve of increasing temperatures afforded by the above figures. The average increase between the measurements at 2,780 feet and 5,820 feet is one degree for each 56.9 feet. At the same rate the temperature at 6,007 feet would be 171.7 degrees. The increase between the measurements of 4,380 and 5,820 feet is more applicable and also believed to be nearer normal, being one degree for a little less than 51 feet, and projecting this downward for the balance of 187 feet gives a figure of 172 degrees for the bottom.

Additional, although less precise, evidence of the underground heat was afforded by the artesian flows that were met in the course of drilling.

The water from the 3,658-foot horizon had a temperature of 80 degrees Fahrenheit as it flowed out at the surface. The 3,820-foot water had a temperature at the well head of 95 degrees Fahrenheit, and later, when the flow from these two horizons mingled, the temperature was 90 degrees Fahrenheit. In the case of both the water was certainly much cooled on the way up.

OCCURRENCE OF WATER IN THE WELL

Stratigraphic range of artesian flows.—Artesian flows of water were encountered in six or seven sandstone horizons in the well, the water being in all cases sweet and potable and of meteoric rather than connate origin. It was found satisfactory for drinking and for use in the boilers and supplied all needs of the camp. The water in several horizons gave much trouble in the drilling, being under such heavy pressure as to prevent its being mudded off. Such flows were expected under the structural conditions prevailing here, with the porous beds rising a few miles to the south and outcropping at the edge of the basin at elevations slightly higher than the site of the well. It was a matter of some surprise that more such flows were not met. The upper four horizons were in the Middle Siwalik, above a depth of 900 feet. The next two horizons (numbers 5 and 6, as listed later) were about 3,000 feet deeper, below the main mass of the fine-grained Chinji formation, within the zone, about 250 feet thick, which may be considered as transitional between the Chinji above and the coarser Kamlial below. With one possible exception (horizon 7, as listed later), the failure to find important water sands within the Kamlial, where they might have been expected most of all, is noteworthy, inasmuch as approximately 1,000 feet of these predominantly sandstone beds outcrop on the north flank of the Salt Range, on the south edge of the basin, as just mentioned, and are not only exposed to a fair rainfall (about 15 to 30 inches per annum), but are crossed at right angles by numerous rivulets that descend the ravines of the Salt Range. A probable explanation of the lack of notable water sands in the Kamlial is that many of these sandstone beds, throughout the thickness of the formation on the north flank of the Salt Range, show an impregnation with oil at their outcrop. This may act as a seal in the case of the more porous beds, preventing their absorbing surface waters. Evidence in support of such an explanation is afforded by the Ghabir River well, drilled by the Attock Oil Company near the foot of the Salt Range, three miles southwestward from the Jhatla well. It penetrated the basal few hundred feet of Chinji beds and the whole of the Kamlial, where they are dipping 11 to 12 degrees northward off the

Salt Range, and is reported to have found practically no water in either formation, whereas several tar sands were met. On the other hand, an artesian flow of water (acid and saline), with a closed pressure of 200 pounds per square inch, was reported in the upper part of the similarly northward-dipping Nummulitic limestone series below. In the Jhatla well the latter was not found water-bearing.

The water horizons.—The occurrences of water were as follows:

1. Depth, 44 feet; a small stream of water from sandstone.
2. Depth, 160-165 feet; approximately 420 gallons an hour.
3. Depth, 370-377 feet; minor influx of water.
4. Depth, 850-860 feet; roughly 250 gallons an hour. The combined flow from horizons 2, 3, and 4 for the first month after horizon 4 was encountered was between 600 and 670 gallons per hour. A year later it was between 550 and 600 gallons.
5. Depth, 3,658 to 3,673 feet; initial flow at rate of over 4,000 gallons per hour, declining within a few hours to 670 gallons per hour and to about 400 gallons per hour after two days. This rate continued nearly three weeks, but then declined at the end of the first month to 325 gallons per hour. At the end of the second month the flow was 270 gallons per hour and four and a half months after it was struck the flow had declined to about 150 gallons per hour.

   During the first few weeks at least this water was under a pressure of about 500 pounds per square inch at the well head. After two months, although it was not measured, there were indications of the pressure being reduced about 40 per cent.
6. Depth somewhat less than 3,841 feet, probably from the thick zone of gray sandstone at about 3,820 feet. The original flow was 1,400 gallons per hour and the established flow for the first month approximately 1,250 gallons per hour. After two months it was about 1,130 gallons per hour. After four months (over six months from the date of horizon 5) the combined flow from this and horizon 5 was 1,200 gallons per hour, and the yield of these continued to supply the drilling camp with water for all purposes until the well was abandoned (more than sixteen months from the date of horizon 5).

   The pressure of this water at the well head was measured as at least 480 pounds per square inch and probably something more.
7. At a depth between 4,350 and 4,400 feet there may have been a water sand yielding a flow of about 250 gallons an hour. There appeared to be an increment of about that amount to the flow from horizons 5 and 6, but owing to the drilling conditions the flow from 5 and 6 was subject to fluctuations, and circumstances did not permit a definite determination as to whether a new flow was struck here. In any case there was no change in the character of the water.

Other beds containing considerable water may possibly have been passed through, but artesian flows were not detected at any point except those mentioned, and it is not believed that any major source was missed.

In the portion of the well below 4,400 feet the coarser sandstone beds were generally found to be moist, but the finer beds, on the contrary, almost dry.

Cause of pressure of artesian flows.—The pressure of about 500 pounds per square inch, measured at the well head, in the case of the water from horizon number 5 from 3,658 feet, and similarly in the case of the 3,820-foot horizon (number 6), was abnormally high, considering the elevation of the source beds at their outcrop. In noting this, Mr. Eastman reported that "at no other place sufficiently close to Jhatla to influence the pressure of artesian waters here do the Kamlial formation and the sands just above the Kamlial attain the height and consequent artesian head that obtains along the Salt Range. We must look, therefore, for factors other than artesian head to explain the excessive pressure." He inclined to the view that the water sands were comparable with quicksand, and that the water was for a time squeezed out under "rock pressure" when the well opened a vent. Mr. Condit made the following interesting comments and suggestion of one possible explanation:

"The water pressures recorded are at least 300 pounds in excess of what would be expected were they due merely to normal hydrostatic head. The surface at the well is 1,740 feet in elevation and the nearest outcrops of Kamlial and lower Chinji to the south are at about 2,100 feet in the valley floors cut through the formations, giving a head of only 360 feet, which would normally account for about 160 pounds pressure. The water column for a pressure of 500 pounds would be about 1,135 feet, which, added to the elevation at the well, gives 2,975 feet. This is the approximate elevation of the Kamlial beds in the several places where they extend up the dip slopes to the crest of the Salt Range adjacent to Jhatla.

"Such coincidence in the height of the Kamlial beds on the crest of the Salt Range with the height required to give the head registered at Jhatla suggests that the water pressure may be an 'inherited' one—that is, handed down from the time when the Kamlial and overlying formations had not been denuded from the higher portions of the Salt Range. Possibly the waters in the rocks beneath Jhatla may have been 'locked up' through partial cementation of the interspaces in the sandstones up the dip near the outcrop, thus preventing adjustment of pressure that would normally follow as erosion of the water-bearing beds from the upper slopes of the Salt Range proceeded. If this explanation is true, it should follow that the pressure and volume of water from the well will gradually decrease. . . . The amount of gas issuing at any time has been too slight to assume that it has any part in creating the pressure."

It is to be noted that the volume of the flows, and apparently also the pressure, did decline. Mr. Condit suggested filling of pore space in the strata near their outcrop through cementation by ground waters. It is

also possible that oil acted as a sealing agency, and the hypothesis is rendered even more plausible by the fact that many of the beds of the Kamlial and lower Chinji may actually be observed at their outcrop as filled with oil residues. The oil has its source in the Nummulitic series and has migrated up through about 1,300 feet of beds, through the whole Kamlial and for at least 200 feet into the Chinji—that is, to just about the horizon of the artesian water sands in question. The idea that sealing by oil has acted to retain a super normal pressure of water in the lower beds of the Chinji may seem contradictory to the one previously suggested, that such sealing accounts for the scarcity of water in the Kamlial; but the seeming contradiction can be met by the highly probable assumption that the oil gathered in the Kamlial beds at an early stage of the Salt Range anticlinal folding before the beds were uncovered, whereas migration progressed upward into the Lower Chinji only at a later stage, after deformation and erosion had proceeded further and after the latter had become exposed to meteoric agencies. It is to be noted that superficial cementation of the exposed beds, with oil or otherwise, would have to be a continuing process concurrent with erosion and sufficiently in advance of erosion to prevent escape of the water. This does not appear an improbable condition, especially if oil is considered as the cementing agency.

In conclusion, it should be added that the above "inherited pressure" hypothesis is only put forward as an interesting and suggestive possibility. Evidence is not at hand to prove what is the true explanation of the pressure observed in these artesian flows.

Character of the water.—The water from all horizons was clear, suitable for drinking and use in the boilers, and not varying greatly in character.

I. An analysis of the mingled water from horizons 2 and 3 (160 and 370 feet) and a separate analysis of that from horizon 4 (850 feet) showed them approximately alike, as follows:

Basic Radicles in Solution	*Acid Radicles in Solution*
Na, K in excess of strong acids.	Cl and SO_4 in about equal amounts.
Some Ca.	Considerable CO_3.
Trace of Mg.	

A trace of organic matter. No silicic acid, Al, Fe, nitrates, nor nitrites.
Primary salinity (bulk).
Secondary alkalinity.
Primary alkalinity (slight).

Weight of Total Salts in Solution

Horizons 2 and 3: 100 cubic centimeters of water, brown residue .064 gram.
Horizon 4: 100 cubic centimeters of water, brown residue, .086 gram.

II. The following are analyses of the water from horizons 5 (3,658 feet) and 6 (3,820 feet):

	Horizon 5		Horizon 6	
Total solids per 100 cubic centimeters	.181 gram (approximate). Residue brown on evaporation. Some organic matter probably present.		.173 gram (approximate). Residue white.	
	Per cent weight.	Value.	Per cent weight.	Value.
Cl'	33.5	.9497	21.5	.6063
SO_4''	16.3	.3432	15.9	.3307
CO_3''	10.9	.3629	21.8	.7259
Total acid radicles		1.6508	....	1.6629
Na', K	38.3	1.6617	39.6	1.7226
Ca''	traces		traces	
Mg''	traces		traces	
Total basic radicles		1.6617		1.7226
SiO_2	.7		.3	
Iron	traces		traces	
Al_2O_3, nitrates or nitrites	none		none	
Primary salinity	68.		42.	
Primary alkalinity	21.		57.	
Secondary alkalinity	trace		trace	

LOG OF JHATLA WELL

In reading the log of the Jhatla well the following abbreviations are used:

(Ss. = sandstone; sls. = siltstone; "pseudo-congl." = "pseudo-conglomerate"; calc. = calcareous; rd. br. = reddish brown; purpl. br. = purplish brown.)

Depth in feet		Thickness in feet	
From	To		
0	9	9	Surface, coarse sand.
9	44	35	Reddish brown siltstone.
44	90	46	Sandstone. Small stream of fresh water entering a little below 40 feet.
90	100	10	Compact sand and sls.
100	118	18	Ss.
118	135	17	Rd. br. sls.
135	160	25	Ss.
160	187	27	Compact sand. Well yielding about 10 barrels of fresh water per hour at 160 feet.
187	218	31	Ss.
218	230	12	Bluish sls.
230	265	35	Rd. br. sls.

Depth in feet		Thickness in feet	
From	To		
265	280	15	Bluish sls. (Down to 300 feet the description is based on the driller's log, prior to the arrival of a geologist to watch the results.)
280	302	22	Ss.
302	308	6	Rd. br. sls.
308	337	29	Sandy sls.
337	345	8	Fine-grained ss.
345	350	5	Coarse gray "pepper and salt" ss.
350	370	20	Gray silty ss.
370	376	6	Coarse gray ss. with fresh water.
376	410	34	Gray silty ss.
410	420	10	Gray "pepper and salt" ss. with some sls.
420	440	20	Gray silty ss.
440	465	25	Gray ss. with some sls.
465	480	15	Coarse gray ss.
480	496	16	Gray ss. with some sls.
496	500	4	Coarse gray ss.
500	518	18	Gray silty ss.
518	520	2	Coarse gray ss.
520	535	15	Gray silty ss.
535	550	15	Gray calcareous ss. with some sls.
550	560	10	Predominantly brown sls., but with streaks or lumps of gray ss.; resembles "pseudo-conglomerate."
560	605	45	Rd. br. sls. and ss.
605	620	15	Gray ss. with some red sls.
620	640	20	Rd. br. sls.
640	650	10	Gray calc. ss.
650	665	15	Rd. br. sls.
665	685	20	Silty ss.
685	715	30	Gray ss.
715	742	27	Hard, calc., silty ss.
742	762	20	Hard calc. ss. with streaks of rd. br. sls. Boulderlike inclusions of gray ss. and sls. "Pseudo-congl." in part.
762	775	13	"Pseudo-congl."
775	813	38	Rd. br. sandy sls. with streaks of "pseudo-congl." between 791 and 810 feet.
813	820	7	Gray, calc., sandy sls.
820	832	12	Rd. br. sandy sls. with some "pseudo-congl." between 825 and 830 feet.
832	836	4	Gray, calc., sandy sls.
836	837	1	Rd. br. sls.
837	840	3	Gray, calc., sandy sls.
840	845	5	Rd. br. sls.
845	850	5	Gray, calc., silty ss.

Depth in feet		Thickness in feet	
From	To		
850	860	10	Soft gray ss. Water sand. Flow roughly 6 barrels per hour of fresh water.
860	875	15	Gray to red, calc., sandy sls.
875	900	25	Gray, calc., silty ss. containing boulderlike inclusions of ss.
900	910	10	Rd. br. sandy sls.
910	918	8	Gray, calc., silty ss.
918	936	18	Rd. br. sls.
936	942	6	"Pseudo-congl." Red ss. matrix with angular pebbles of ss. and sls.
942	946	4	Red sandy sls.
946	970	24	Gray silty ss. with hard calc. streaks.
970	974	4	Chocolate-brown sls.
974	990	16	Gray, silty, calc. ss.
990	992	2	"Pseudo-congl." Gray ss. matrix with angular ss. and sls. pebbles.
992	994	2	White to gray calc. ss.
994	1,001	7	Chocolate-brown silty ss. with "pseudo-congl." streaks in upper part.
1,001	1,027	26	Gray, silty, calc. ss.
1,027	1,044	17	Reddish sls. grading to yellowish sandy sls.
1,044	1,107	63	Gray silty ss.
1,107	1,110	3	Yellowish sls.
1,110	1,148	38	Yellowish sandy sls.
1,148	1,153	5	Gray silty ss.
1,153	1,161	8	Red sls.
1,161	1,165	4	Sandy limestone (or calc. ss.).
1,165	1,175	10	Yellow to red sls.
1,175	1,179	4	Red sls.
1,179	1,195	16	Red "pseudo-congl." (small ss. and sls. pebbles in a silty matrix).
1,195	1,205	10	Yellow sandy sls. with pebbly streaks, like above.
1,205	1,220	15	Red sandy sls. with pebbly streaks, like above.
1,220	1,239	19	Yellow sandy sls.
1,239	1,267	28	Gray silty ss.
1,267	1,273	6	Grayish white sandy limestone.
1,273	1,278	5	Gray, calc., silty ss.
1,278	1,283	5	Red sls.
1,283	1,305	22	Yellow to red sls. with considerable gravel of ss. and sls. pebbles.
1,305	1,311	6	Gray, tough, silty, calc. ss.
1,311	1,320	9	Red sls.
1,320	1,325	5	Yellowish brown slightly sandy sls.
1,325	1,328	3	Brown sandy sls.
1,328	1,358	30	Predominantly gray silty ss.
1,358	1,366	8	Ss. with streaks of red sls.

Depth in feet		Thickness in feet	
From	To		
1,366	1,395	29	Gray soft ss.
1,395	1,420	25	Red to gray sandy sls.
1,420	1,431	11	Gray ss.
1,431	1,436	5	Red to gray sandy sls.
1,436	1,443	7	Fine-grained gray ss.
1,443	1,455	12	Red sls.
1,455	1,459	4	Fine gray ss.
1,459	1,461	2	Red sls.
1,461	1,478	17	Fine to coarse gray ss.
1,478	1,481	3	Red sls.
1,481	1,497	16	Gray ss. (streaks of sls.?).
1,497	1,502	5	Red sls.
1,502	1,514	12	Coarse gray ss.
1,514	1,537	23	Soft red sls.
1,537	1,558	21	Sls. with streaks of ss.
1,558	1,563	5	Red sls. with pebbly layers.
1,563	1,653	90	Mainly red sls. with minor beds of ss. ranging up to probably not more than 2 to 3 feet thickness.
1,653	1,698	45	Dominantly red sls.
1,698	1,703	5	Red sls. with streaks of ss.
1,703	1,726	23	Red sls.
1,726	1,741	15	Ss. with streaks of sls.
1,741	1,785	44	Dominantly soft red sls.
1,785	1,857	72	Mainly red sls. with minor beds of ss.
1,857	1,870	13	Ss. with minor beds of sls.
1,870	1,878	8	Hard calc. sls.
1,878	1,902	24	Mainly fine ss. with minor beds of sls.
1,902	1,904	2	Tough pebbly sls. ("pseudo-congl.").
1,904	1,916	12	Ss.
1,916	1,921	5	Red sls.
1,921	1,926	5	Ss.
1,926	1,937	11	Sls. and ss.
1,937	1,960	23	Red sls. with some ss.
1,960	1,978	18	Fine gray ss.
1,978	2,005	27	Gray ss.
2,005	2,068	63	Red sls. with streaks of ss.
2,068	2,100	32	Gray ss. with streaks of sls.
2,100	2,122	22	Tough red sls. A light yellow sls. layer at 2,120 feet showed a slight amount of anhydrite on analysis.
2,122	2,155	33	Red sls. with streaks of ss.
2,155	2,161	6	Silty ss.
2,161	2,180	19	Red sls. with streaks of ss.
2,180	2,190	10	Tough, gray, fine ss.
2,190	2,221	31	Tough, red, nodular or "pseudo-conglomeratic" sls.
2,221	2,230	9	Soft red sls.
2,230	2,435	205	Red sls. with minor beds of ss.

Depth in feet		Thickness in feet	
From	To		
2,435	2,444	9	Sandy sls.
2,444	2,452	8	Gray ss.
2,452	2,470	18	Red sls. with minor beds of ss.
2,470	2,526	56	Dominantly red sls.
2,526	2,529	3	Extra hard, red, sandy sls.
2,529	2,542	13	Red sls.
2,542	2,552	10	Sandy red sls.
2,552	2,559	7	Tough red sls.
2,559	2,594	35	Gray fine ss. (with streaks of sls.?).
2,594	2,599	5	Fairly hard red sls.
2,599	2,631	32	Dominantly gray ss., fine.
2,631	2,725	94	Alternating beds of ss. and sls.
2,725	2,741	16	Red sls.
2,741	2,751	10	Red sls. with layers of ss.
2,751	2,760	9	Thin beds of ss. and sls.
2,760	2,774	14	Mainly ss. with layers of sls.
2,774	2,790	16	Hard, calc., red sls.
2,790	2,862	72	Dominantly red sls. with minor ss. beds between 2,824 and 2,852 feet.
2,862	2,894	32	Hard, calc., red sls.
2,894	2,924	30	Red sls.
2,924	2,932	8	Hard, brown, fine ss.
2,932	2,944	12	Soft red sls.
2,944	3,031	87	Generally hard, calc., red sls. with minor beds of tough calc. ss., "pseudo-congl." in part.
3,031	3,066	35	Gray silty ss. and sandy sls.
3,066	3,142	76	Red sls. with minor beds of ss.
3,142	3,144	2	Hard gray ss
3,144	3,186	42	Alternating thin beds of ss. and red sls.
3,186	3,214	28	Red sls. with minor beds of ss.
3,214	3,232	18	Hard, calc., gray ss.
3,232	3,329	97	Gray fine to medium grained calc. ss. interbedded with minor beds of sls.
3,329	3,384	55	Alternating thin beds of ss. and sls.
3,384	3,430	46	Mainly ss. with considerable sls.
3,430	3,465	35	Dominantly sls., red.
3,465	3,489	24	Red sls. with minor beds of ss.
3,489	3,520	31	Red sls.
3,520	3,528	8	Hard, red, sandy sls. Abundant calcite fragments indicate beds are veined. (No calcite higher up in well.)
3,528	3,550	22	Red sls. with considerable ss.
3,550	3,588	38	Hard, red sandy sls.; calcite fragments.
3,588	3,593	5	Hard, coarse, gray ss.
3,593	3,616	23	Alternating thin beds of ss. and sls.
3,616	3,636	20	Red sls. with considerable ss.
3,636	3,658	22	Mainly ss. with minor beds of sls.

Depth in feet		Thickness in feet	
From	To		
3,658	3,673	15	Coarse gray ss. yielding large flow of fresh water.
3,673	3,701	28	Mainly rd. br. sls. with minor beds of ss.
3,701	3,723	22	Medium-grained gray ss.
3,723	3,760	37	Rd. br. sls.
3,760	3,773	13	Gray ss.
3,773	3,827	54	Gray ss. with streaks of hard calc. sls. Easy drilling in ss.
3,827	3,849	22	Thin beds of ss. and sls. Hard drilling. Large flow of fresh water, probably from just above this zone.
3,849	3,856	7	Mainly rd. br. sls.
3,856	3,862	6	Mainly fine ss. with lesser amount of sls.
3,862	3,914	52	Hard rd. br. sls., sandy sls., and some interbedded ss.
3,914	3,922	8	Brown sandy sls.
3,922	3,925	3	Rd. br. sls. and hard ss. bed.
3,925	3,943	18	Hard, fine-grained ss. and coarser soft ss.
3,943	4,021	78	Mainly ss. with lesser amount of sls. interbedded.
4,021	4,039	18	Alternating beds of sls. and ss.
4,039	4,051	12	Predominantly gray ss.
4,051	4,055	4	Rd. br. sls.
4,055	4,076	21	Alternating ss. and sls.
4,076	4,108	32	Rd. br. sls.
4,108	4,115	7	Hard, fine, gray ss.
4,115	4,134	19	Brownish sls.
4,134	4,241	107	Soft zone of rd. br. sls. and gray ss.; no certainty which predominates.
4,241	4,248	7	Gray silty ss.
4,248	4,252	4	Rd. br. sls.
4,252	4,259	7	Fine-grained calc. ss.
4,259	4,319	60	Mainly medium-grained gray ss. with minor amount of brown sls.
4,319	4,323	4	Hard, fine-grained ss.
4,323	4,339	16	Alternating ss. and sls. (probably ss. predominates).
4,339	4,348	9	Mainly fine gray ss.
4,348	4,374	26	Alternating ss. and sls.
4,374	4,401	27	Mainly hard gray silty ss.
4,401	4,413	12	Hard, gray, medium-grained to coarse ss. (Diamond drilling and coring commences at 4,401 feet.)
4,413	4,416	3	Hard, gray, medium-grained to coarse ss. with streaks of purplish "pseudo-congl." made mostly of particles of sandy sls.
4,416	4,418	2	"Pseudo-congl."
4,418	4,424	6	Coarse gray ss. with 1 foot hard, fine, gray ss. in middle.
4,424	4,427	3	Hard gray sandy sls.
4,427	4,439	12	Hard gray silty ss. with streaks of "pseudo-congl." composed largely of sls. flakes.

Depth in feet		Thickness in feet	
From	To		
4,439	4,445	6	Hard gray silty ss. with streaks of rd. br. to purple sls. and "pseudo-congl."
4,445	4,450	5	Irregular purple sls. particles cemented in matrix of hard, bluish, sandy limestone.
4,450	4,459	9	Rd. br. to purple sandy sls.
4,459	4,462	3	Hard fine gray ss.
4,462	4,472	10	Alternating gray ss. and rd. br. sls.
4,472	4,531	59	Medium to coarse-grained ss., with thin partings of purple sls. and streaks of "pseudo-congl."
4,531	4,534	3	Soft, purple, silty ss.
4,534	4,542	8	Rd. br. sls. with streaks of "pseudo-congl."
4,542	4,544	2	Rd. br. silty ss.
4,544	4,563	19	Red sls. with lenses composed of pellets of same material.
4,563	4,587	24	Red to rd. br. sls., sandy in streaks; not so pebbly as above.
4,587	4,589	2	Rd. br. sls.
4,589	4,599	10	Very hard, dense ss.; purplish at top, gray at bottom.
4,599	4,611	12	Fairly hard rd. br. sls. with many streaks of sls. pellets. Full of calcite crystals near base.
4,611	4,622	11	Very hard, dense ss.; purplish grading into gray.
4,622	4,633	11	Rd. br. sls.
4,633	4,643	10	Hard, fine, gray ss. with streaks of purple sls.
4,643	4,647	4	Rd. br. to purple sandy sls.
4,647	4,665	18	Friable, coarse, gray ss.
4,665	4,732	67	Coarse- to medium-grained gray ss. with streaks of hard "pseudo-congl."
4,732	4,734	2	Hard, medium-grained, gray ss.
4,734	4,739	5	Hard calc., "pseudo-congl." sls. particles.
4,739	4,764	25	Red to rd. br. sandy sls.
4,764	4,780	16	Grayish purple silty ss. grading into ordinary gray ss.
4,780	4,795	15	Medium- to fine-grained gray ss.
4,795	4,804	9	Probably same ss. (Core lost in hole.)
4,804	4,817	13	Medium-grained gray ss.
4,817	4,864	47	Fine to coarse-grained gray ss. with streaks of "pseudo-congl." and brown sls.
4,864	4,879	15	Soft, rd. br. to purple sandy sls.
4,879	4,915	36	Medium-grained to coarse gray ss., with lenses of "pseudo-congl." composed of sls. particles in limestone matrix.
4,915	4,970	55	Coarse to medium-grained gray ss. with a few streaks of the "pseudo-congl." between 4,940 and 4,967 feet.
4,970	4,984	14	Rd. br. nodular sls.; greenish calcite stringers.
4,984	4,986	2	Probably calcareous ss.

Depth in feet		Thickness in feet	
From	To		
4,986	4,998	12	Hard, dense, medium-grained, gray calc. ss. Stringers and nodules of white calcite and one or two angular inclusions of brown ss.
4,998	5,002	4	Rd. br., sandy, nodular sls.
5,002	5,007	5	Hard, calc. ss.
5,007	5,040	33	Medium-grained to fine gray ss. becoming coarser toward base. Finer ss. is hard and calc.; coarser is soft and wet.
5,040	5,066	26	Coarse, soft and wet gray ss. with "pseudo-congl." at base.
5,066	5,084	18	Bluish sls. grading into rd. br. sls.
5,084	5,097	13	Red to rd. br. sls.; calc. nodules.
5,097	5,128	31	Same as above, grading down into purplish sls. with streaks of ss.
5,128	5,131	3	Gray to purplish brown, fine, silty ss.
5,131	5,149	18	Gray ss., in part coarse, but mainly fine, and in part silty; streaks of sls.
5,149	5,155	6	Rd. br. to purple sandy sls.
5,155	5,159	4	Brown silty ss.
5,159	5,224	65	Gray, coarse to medium-grained ss.; coarse ss. in upper part is noticeably wet; streaks of "pseudo-congl." in lower part.
5,224	5,239	15	Rd. br. nodular, sandy sls. grading down into the following.
5,239	5,243	4	Purpl. br. silty ss. with calcite stringers; this grades down into following.
5,243	5,271	28	Gray, mainly coarse ss. with irregular lenses of sls.
5,271	5,311	40	Gray, medium-grained to coarse ss.
5,311	5,316	5	Purpl. br. to gray, calc., silty ss. and "pseudo-congl." in which pebbles are mostly of soft brown sls.
5,316	5,326	10	Purpl. br. sls. with silty limestone nodules and sandy layers.
5,326	5,336	10	Sandy, finely micaceous sls.
5,336	5,345	9	Gray, medium coarse ss. with layers full of brown sls. particles and calc. pellets.
5,345	5,360	15	Gray, medium coarse ss. with scattered pellets of brown sls.; much mica.
5,360	5,408	48	Gray, medium coarse ss.
5,408	5,413	5	Gray ss. with pellets of soft brown sls. and calc. sls.; grades down into greenish and brown sls. with calc. pellets.
5,413	5,445	32	Purpl. br. to rd. br. and chocolate-colored sls., in part sandy and with scattered calc. pellets and nodules; slickensides noted in upper few feet.
5,445	5,486	41	Gray, and in upper part brownish, medium-grained ss.: much dark mica between 5,456 and 5,472 feet.

Depth in feet		Thickness in feet	
From	To		
5,486	5,506	20	Purpl. br. sls. in part sandy and with scattered calc. nodules.
5,506	5,507	1	Brownish gray ss.
5,507	5,509	2	Greenish gray ss. with sls. pellets.
5,509	5,515	6	Purpl. br. sandy sls. with green mottling in upper part.
5,515	5,533	18	Rd. br. sls. with calc. pellets and a one-foot layer of calc. sandy sls. at base.
5,533	5,540	7	Purpl. br. to grayish, minutely cross-bedded, silty ss.
5,540	5,543	3	Brownish gray medium-grained ss.
5,543	5,544	1	Purpl. br. sls.
5,544	5,555	11	Purpl. br. medium-grained ss. with ferruginous sls. band.
5,555	5,575	20	Gray ss.; upper part medium-grained, lower part sub-medium grained.
5,575	5,578	3	Purpl. br. sandy sls.
5,578	5,584	6	Gray, medium coarse to medium-grained ss., with brown sls. pebbles in upper part.
5,584	5,586	2	Dark gray, fine-grained ss., minutely cross-bedded.
5,586	5,595	9	Gray, medium coarse-grained ss. with scattering of large and small sls. pebbles in upper 5 feet.
5,595	5,603	8	Gray medium coarse to fine-grained ss.
5,603	5,605	2	Gray "pseudo-congl." with pebbles of grayish to purpl. br. calc. sls.
5,605	5,626	21	Gray, medium coarse to coarse-grained ss. with few small scattered sls. pebbles.
5,626	5,638	12	Gray ss. with irregular "pseudo-congl." layers containing pebbles of sls. and calc. ss.; thin coal film.
5,638	5,639	1	Purpl. br., hard, sandy sls.
5,639	5,644	5	Gray calc. ss. with "pseudo-congl." layers of mixed ss. and sls. pebbles; three inches brown sls. at base.
5,644	5,656	12	Gray, medium coarse ss.
5,656	5,661	5	Purpl. br. calc. finely sandy sls. with calc. pellets.
5,661	5,666	5	Purpl. br. sandy sls.
5,666	5,674	8	Purpl. br. to grayish medium-grained ss. with "pseudo-congl." streaks containing small calc. pebbles.
5,674	5,702	28	Purpl. br. sls. with a few green lumps, finely sandy layers, and lime pellets.
5,702	5,720	18	Purpl. br. calc. sls., slightly sandy in some layers and with lime pellets; showing of non-inflammable gas.
5,720	5,724	4	Purpl. br. ss. with gray nodules of calc. ss.
5,724	5,726	2	Purpl. br. calc. sls. with gray lime pellets.
5,726	5,742	16	No record; core lost in well.
5,742	5,761	19	Probably all purpl. br. sls.; only 10 feet of core obtained.
5,761	5,763	2	Purpl. br. silty ss.
5,763	5,771	8	Gray ss. of medium to medium coarse grain with purpl. br. mottling.

Depth in feet		Thickness in feet	
From	To		
5,771	5,773	2	"Pseudo-congl.," made up of yellowish ochreous sls. pebbles in sandy calc. matrix.
5,773	5,782	9	Purpl. br. ss., upper part silty and fine grained, grading down into medium coarse and calc. ss.
5,782	5,811	29	Gray ss., medium grained in upper part and coarse toward base; tough to friable; cross-bedding prominent in some layers.
5,811	5,816	5	Gray ss. with scattered pebbles of sls.
5,816	5,822	6	"Pseudo-congl." with ochreous yellow to gray, hard, calc. pebbles.
5,822	5,829	7	Gray coarse to medium-grained ss. with sls. pebbles.
5,829	5,831	2	"Pseudo-congl." of yellow to brown calc. sls. pebbles in a limy sand matrix.
5,831	5,837	6	Purpl. br. finely sandy sls. with streaks of ss.
5,837	5,839	2	"Pseudo-congl." with brown and gray calc. sls. pebbles. One fragment suggests fossil wood.
5,839	5,869	30	Purpl. br., medium-grained to fine, silty ss. with streaks of gray ss. and layers of sls.
5,869	5,886	17	No record; core lost in well.
5,886	5,889	3	Purpl. br. hard sls.
5,889	5,893	4	Purpl. br. sls., varyingly sandy and with fine sand laminæ.
5,893	5,902	9	Purpl. br. to gray, coarse to medium-grained ss., with scattered sls. pebbles.
5,902	5,908	6	Gray to purpl. br. calc. conglomerate with irregular pebbles of impure limestone and sls.; traces of possible fossils.
5,908	5,912	4	Purpl. br. to gray ss. with conglomeratic layers.
5,912	5,925	13	Purpl. br., partly sandy sls. with small brown lime pellets (only 8 feet of this preserved in core).
5,925	5,931	6	Cherty gray limestone and gray calc. clay shale with small dots of pyrite in the cherty rock. Typical of "Nummulitic limestone" (Eocene).
5,931	5,938	7	Gray to dark gray fossiliferous limestone, with scattered dots of pyrite.
5,938	5,942	4	Dark gray, compact, somewhat siliceous limestone; almost devoid of fossils.
5,942	5,955	13	Mostly light blue, calc. clay shale with thin layers and nodules of richly fossiliferous limestone. Nummulites, etc.
5,955	5,960	5	Dark gray, compact, clayey limestone with a few fossils and with scattered dots of pyrite. Rock has petroleum odor and gives a small amount of oil when treated with solvent.

Depth in feet		Thickness in feet	
From	To		
5,960	5,975	15	Fossiliferous calc. clay shale and shaly limestone with abundant small dots of pyrite. Fossils mostly small radiate Nummulites. Beds disintegrate readily and only 8 feet of core brought up.
5,975	5,983	8	Gray limestone, richly fossiliferous in upper part; well preserved, large foraminifera. Dry oil residue on joint planes and impregnating some beds.
5,983	5,988	5	Bluish gray clay shale with calc. fossiliferous bands. Foraminifera and a small smooth species of ostracod are common.
5,988	5,995	7	Very fine, yellow-white, calc. ss., alternating with calc. fossiliferous clay shale; several fish teeth; crystals of pyrite up to half inch in diameter; slickensided joint planes.
5,995	6,007	12	Argillaceous and pyrite-bearing limestone. Intermittent showing of noninflammable gas from lower portion of well.

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STRUCTURE OF THE MUD BUTTES AND TIT HILLS IN ALBERTA[1]

BY GEORGE SLATER[2]

(Read before the Society by David White December 29, 1926)

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INTRODUCTION

Superficial disturbances of the country rock associated more or less with drift deposits are of common occurrence in glaciated regions, but are of especial interest in those areas where the strata are composed of comparatively soft outcrops of the Mesozoic and Cainozoic formations. Classical examples of such disturbances occur in Europe in the Island of Möen (6) and the coast sections at Lønstrup, Denmark (7); in the Isle of Rügen, Germany, and the Norfolk coast of Britain. Detailed study of these sections proves that the disturbed deposits have a definite tectonic structure, the repetition of deposits associated with thrust-planes producing beautiful examples of imbricate structure, or "Schuppen-Struktur," due to obstruction to movement of an ice-sheet overloaded with englacial material.

[1] Manuscript received by the Secretary of the Society January 14, 1927.
[2] Introduced by David White.

Similar, but little-known, disturbances occur in Canada, in east-central Alberta, over a wide area of Upper Cretaceous strata; but, unlike the European examples, the disturbances occur in isolated and partially exposed sections, in groups of low hills which rise a few hundred feet above the surrounding plains. The Mud Buttes, which form the subject of the present paper, may be regarded as type sections of this area.

The value of these sections lies in the fact that while the structure as a whole agrees with the principles of glacial tectonics as formulated from other disturbed areas (3, 4, 5), they throw additional light on the relationship between flow-structure and folds produced by directed concentrated pressure; hence the Mud Butte sections are supplementary to particular portions of the structure shown in the much more extensive and complete coast sections of the Lønstrup area (7) and Rügen.

Geology of the Area

The Mud Buttes are a group of low hills one mile long and half mile broad, situated 9 miles south of Monitor, a station on a branch of the Canadian Pacific Railway. Their summit is bounded by the 2,500-foot contour and the eroded floor by the 2,400-foot contour, the sections exposed being unusually clear and of great interest.

The geology of the district is known from the sections in these and similar hills, where the strata, however, are usually disturbed, and from the logs of oil wells in the surrounding district (1).

The succession of the Upper Cretaceous in central and eastern Alberta is as follows:

4. **Edmonton formation: Fresh and brackish water, sandstone, shales, clays, ironstone, coal seams, etcetera.**
3. **Bearpaw formation: Marine, essentially shales, becoming brackish toward the North Saskatchewan River.**
2. **Belly River formation: Interbedded sandstones and shales, ironstone, coal; fresh and brackish water.**
1. **Benton (Colorado group): Marine shale with limestone and sandstone beds.**

(Note.—Numbers 3 and 4 are missing in the Mud Butte area, the marine shales of the Bearpaw formation outcropping to the south.)

Two wells have been sunk in the immediate neighborhood of the Mud Buttes—the West Regent well, near Monitor, to the north, and the Misty Hills well to the south; the distance between them is 11 miles, the Mud Buttes lying midway between the two. In the former the base of the Benton shale, the most reliable datum line, occurred at a depth of 315 feet, and in the latter at 389 feet below sealevel, giving a dip to the south of 7 feet per mile, which is normal to the area.

The log of the upper part of the Misty Hills well may be summarized as follows:

Log of upper Part of the Misty Hills Well

Drilled by the Imperial Oil Company

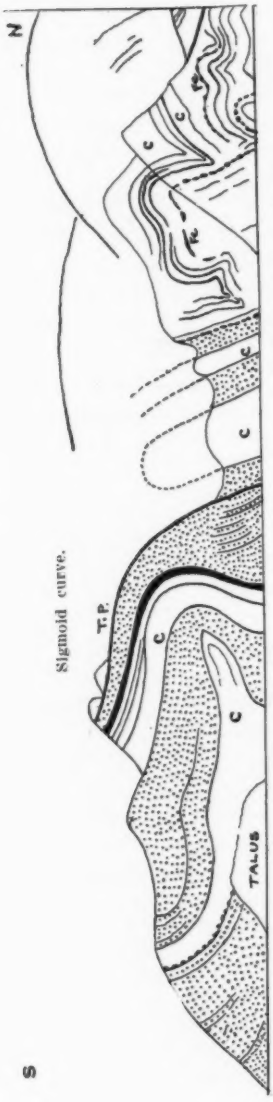
Depth of well, 3,304 feet.
Location, northeast quarter of section 29, township 32, range IV west of fourth meridian.
Station, Monitor, Alberta, Canadian Pacific Railway, 14 miles to location.
Elevation, 2,451.1 feet above sealevel.

Prepared by Dr. J. S. Stewart

Depth Feet	Formation
49-55	Fine-grained light gray to buff siliceous sand, with small coal.
55-95	As above, with gray clay.
95-110	Fine gray sand, with much gray argillaceous material.
110-490	Soft light slate gray sandy clay (gumbo), with light calcareous material at a depth of between 145-165 feet, which is disturbed to some extent.

The upper series of beds correspond generally with the disturbed deposits of the Mud Buttes, while the top of the gumbo clay, if *in situ*, is some 20 feet below the eroded floor of the Mud Buttes, but outcrops to the north of these hills and is undisturbed in the lower ground. It is, therefore, fair to assume that the gumbo clay was originally overlain by an outcrop of the upper series of mixed lithology. "The strata of the Mud Buttes belong to the Pale Beds, the upper division of the Belly River formation, of Middle Montana age, and consist of a series of interbedded sands, sandy clays, and lignite clays with ironstone bands. The beds show a prevailing dip of about 30 degrees to the north-northeast and generally strike from north 80 to 110 degrees east. The same series of beds is repeated several times by the miniature folds and thrust-planes which run through the hills in a general east-west direction" (1). This anomalous dip, so strikingly at variance with that of the country rock, places these deposits in the same category as those I have described elsewhere, which exhibit the tectonics of a stagnant glacier (7).

A feature of interest in the Mud Butte sections is the fact that the disturbed beds are uncontaminated with drift, the latter being confined to lower ground and only occurring in the disturbed area as superficial boulders. This freedom from contamination of disturbed and transported lenticles of the country rock has been described from other areas (5).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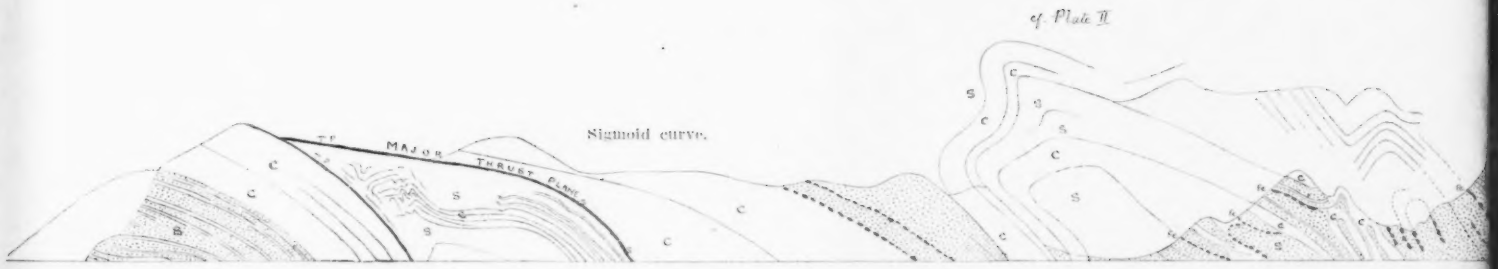

FIGURE 1.—*Section across the*

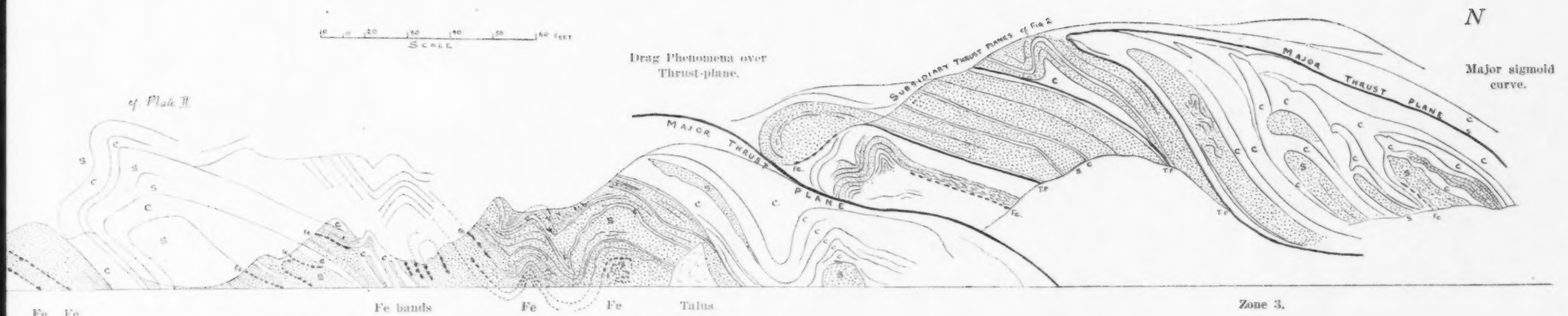

FIGURE 1.—*Section across the Mud Buttes, Alberta*

FIGURE 1.—SOUTH END OF BLUFF OF ZONE 1
Composed of interbedded sands and clays, associated with thrust planes.

FIGURE 2.—FLOW-OVERFOLD OF ZONE 2 FLANKED BY CONTORTED BEDS

STRUCTURAL FEATURES OF ZONES 1 AND 2

pyre curve the form of which, however, changes when traced toward the east.

The compressed zone dies out with rippled strata and the upper surface of the structure as a whole forms a well-defined thrust-plane.

(3) The third zone forms the highest ground and consists of sand associated with clay, showing drag and attenuated overfolds, the beds being dissected by a series of fan-shaped thrust-planes. The northerly face forms a major sigmoid curve leading to extensive slips.

Both north and south of these three zones there is a repetition of disturbance, as already indicated.

The Zone of Hummocks

To the east of the Mud Buttes the beds forming zone 3 dip toward the low ground, and the ridges of disturbed material pass laterally first into a series of low anticlines and finally into a series of isolated hummocks of independent dome-shaped structure. This zone clearly lies outside the area of dominant pressure.

Details of the Structure

THE ZONE OF BLUFFS

The clay and sand forming a bluff shows a composite and anomalous structure. Differential movement of transported and redeposited lenticles of material is shown by the presence of thrust-planes associated with contorted banded clays (figure 1).

The structure has clearly been built from below upward, and from south to north. The bluff to the southeast assumes a dome-shaped structure, proving movement in two directions at right angles to one another (plate 16, figure 1).

The sigmoid curve, figure 2, is a definite structural geometric form in glacial tectonics and its well developed outline in these sections is in itself strong evidence of glacial action (4).

THE CENTRAL ZONE OF COMPRESSION

The flow-overfold.—Adjacent to the sigmoid curve is a remarkable overfold outlined in figure 1 and clearly displayed in the cliff adjacent to the line of section, the outcrops of the eroded core being clearly traced. This curve is shown in plate 16, figure 2. It will be noticed that the line of axis of the "kernel" of the curve does not coincide with the general axis, while the peculiar pointed apex is quite unlike a tectonic overfold, but is identical with that developed in glaciers. Such a curve,

for example, has been photographed from the Grasshopper Glacier of the Rocky Mountains and the Paula Glacier of Braganza Bay, Spitsbergen. The curve shows a peculiar combination of drag and flow. The shape of the curve varies when traced westward, where it becomes recumbent and attenuated. Elsewhere only the eroded "roots" of the structure were seen.

The contorted sands and clays.—Evidence of compression is strikingly shown in the adjacent beds (1). The folds consist of sands with intercalated bands of ironstone and clays (figures 1 and 2). Part of the structure has been eroded in figure 1, but toward the west a beautiful diapyre curve was developed 25 feet in height and from 30 to 45 feet in width, the central vertical core consisting of clay (figure 3). Compression of plastic material has often been the subject of experimental investigation, contortions similar to these (9 and 10) sections

FIGURE 3.—*Attenuated Flow Overfold and Diapyre Curve*
S = sand, C = clay, T. P. = thrust-plane, black = core of clay.

having been beautifully illustrated in the Thirteenth Annual Report of the United States Geological Survey (8).

No experimental work due to pressure alone has produced, however, the striking combination of an attenuated flow-overfold combined with or associated with tectonic folds, as in these sections, although each type of structure has been reproduced separately. The one illustrates drag associated with flow; the other indicates compression requiring a considerable overburden. Compared with the succeeding zone 3, the absence of thrust-planes in this zone is noteworthy. The major thrust-plane forming the upper surface of the central area, however, displays its sole beneath the beds forming the highest ground of zone 3 and the similarity of the lower material strongly suggests repetition or imbricate structure.

The third zone, forming the highest ground, has features of especial interest (figure 1). The material involved is of two kinds: (*a*) sands with plant remains associated with thin lenticles of clay, and (*b*) impure calcareous material separated from these deposits by thrust-planes and occurring toward the north, the same calcareous material being found in

the hummocks already mentioned. A possible source of this material is the calcareous horizon which occurs in the upper part of the outcrop of gumbo clay to the north of the area.

A clearer conception of the structure in this zone can be obtained from the section in the adjacent bluff to the west (figure 4). The central feature is a peculiar overfold having a core of clay; the series of associated deposits are separated by a complex of fan-shaped thrust-planes which apparently have their roots in the major sigmoid curve which completes the structure of this zone. Such a combination agrees admirably with the structure of the sigmoid curve described elsewhere.

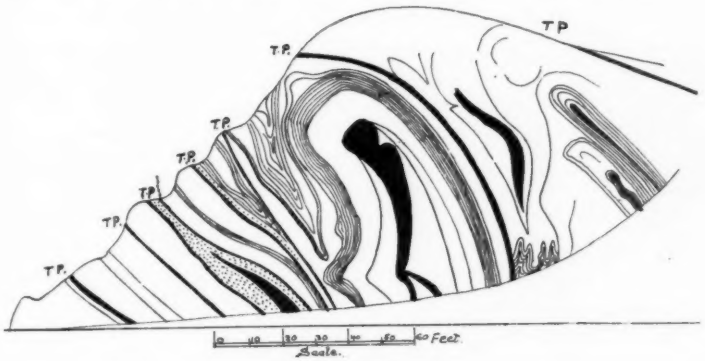

FIGURE 4.—*Zone 3*

Black and fine lines = clay, dotted and blank areas = sand, T. P. = thrust-planes.

Reviewing the thrust-planes in the three zones, it will be noticed that their angles of dip progressively increase from south to north. Such a progressive increase is a feature common to all glacially disturbed deposits.

THE ZONE OF HUMMOCKS

The ridges of material forming zone 3 are slightly deflected southward on reaching the low ground forming the floor of the Mud Buttes to the east.

The east-west anticlines pass into hummocks, which are composed of clay associated with an impure nodular limestone, the latter in some cases forming the bulk of the structure (figures 5, 6, and 7). The hummocks can be studied in three dimensions, and it is clear that their elliptical form is based on the internal structure, although accentuated by erosion.

Their structure is in striking contrast to that already described, and

clearly shows movement in two directions and slight pressure. Lying on the outskirts of the central area, one of great pressure, they are analogous in principle to the zone of ice hummocks described by the author from the Nordenskiöld Glacier of Spitsbergen (2).

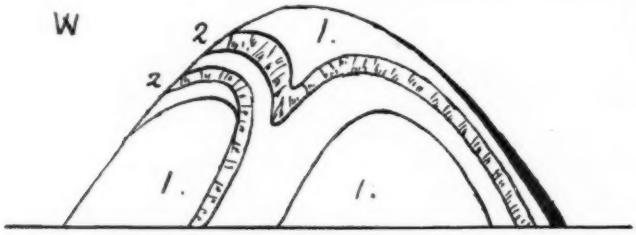

FIGURE 5.—*Isolated Hummock*
The hummock is 34 feet at the base and 18 feet high.

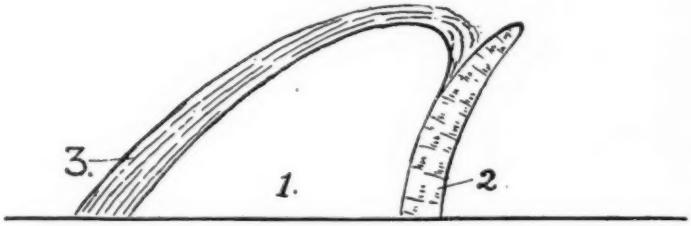

FIGURE 6.—*Cross-section of Hummock*
33 feet at base and 12 feet high. 1 = clay, 2 = nodular limestone, 3 = soft brown clay.

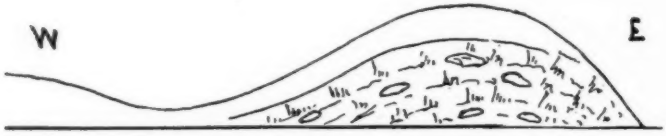

FIGURE 7. —*Hummock with Core of Limestone*

SUMMARY

The evidence that the disturbances are due to ice-action may be summarized as follows:

1. The disturbances are local and superficial.

2. The general dip of the beds is in a direction opposite to that of the general dip of the strata in the district.

3. Differential motion is shown in some of the intercalated beds.

4. A sequence in the structure can be followed when the beds are traced from the south to the north.

5. The form of the overfolds is strikingly analogous to those seen in modern glaciers; the forms of the curved strata in some cases show flow-structure. The contortions of proportions of the compressed area, on the other hand, are due to lateral pressure.

6. The presence of numerous thrust-planes, by means of which differential movement of upper strata over lower (stranded) beds has taken place, recalls ice-movement.

7. The completed topographical feature is in accordance with ice-action. The piling of disturbed and transported lenticles of portions of the country rock through the action of two pressures at different angles to one another is analogous in principle to the movements producing the drumlin structure and to ice-action in Arctic regions; hence a comparatively low topographical feature has been accentuated in height by the deposition of transported material.

8. The peculiar development of hummocky forms is analogous in principle to the production of hummocks of ice in Arctic glaciers.

9. The absence of intercalated drift in the disturbed beds can be paralleled in other glacially disturbed sections elsewhere, deposits of boulder clay usually flanking the older deposits derived from neighboring outcrops.

Acknowledgments

In conclusion, I beg to express my indebtedness to the Imperial Oil Company, Limited, and the Director of the Geological Survey of Canada for furnishing me with copies of the logs of oil wells, and to Prof. John A. Allan, of the University of Alberta, for information on the geology of Alberta. To my chief, Prof. W. W. Watts, I am grateful for giving me facilities for the working out of the results in the Imperial College of Science, London. The cost of this investigation was defrayed by a grant from the Sladen Trustees, 1924, for which I express my thanks.

Literature

(1) 1923. Oliver B. Hopkins: Some structural features of the plains area of Alberta caused by Pleistocene glaciation. Bulletin of the Geological Society of America, volume 34, number 3, pages 419-430.

(2) 1925. George Slater: Observations on the Nordenskiöld and neighboring glaciers of Spitsbergen. Journal of Geology, volume XXXIII, number 4, May-June.

(3) 1926. GEORGE SLATER: Glacial tectonics as reflected in disturbed drift deposits. Proceedings of the Geological Association, volume XXXVII, pages 392-400.

(4) 1927. ———: Part I. The structure of the disturbed deposits in the lower part of the Gipping Valley near Ipswich. Proceedings of the Geological Association, volume XXXVIII, pages 157-182.

(5) 1927. ———: Part II. The structure of the disturbed deposits of the Hadleigh Road area, Ipswich. Proceedings of the Geological Association, volume XXXVIII, pages 183-216.

(6) 1927. ———: The structure of the disturbed deposits of Möens Klint, Denmark. Proceedings of the Royal Society of Edinburgh, volume LV, part II (number 12), pages 289-302.

(7) 1927. ———: The disturbed glacial deposits in the neighborhood of Lønstrup, near Hjørring, North Denmark. Proceedings of the Royal Society of Edinburgh, volume LV, part II, number 13, pages 303-315, plate I.

(8) 1893. BAILEY WILLIS: The mechanics of Appalachian structure. Thirteenth Annual Report of the United States Geological Survey, part II, Geology, pages 217-282.

(9) 1895. E. C. CASE: Journal of Geology, volume 3, pages 918-934.

(10) 1895. W. J. SOLLAS: Quarterly Journal of the Geological Society, volume LI, pages 361-368, figures 1 and 3.

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
VOL. 38, PP. 731-748 DECEMBER 30, 1927

STRATIGRAPHY OF THE NORTHERN SUBPROVINCE OF THE LAKE SUPERIOR REGION[1]

BY T. L. TANTON[2]

(Read before the Society December 27, 1926)

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INTRODUCTION

The work of the Geological Survey of Canada during the past ten years, in the region north of Lake Superior extending westerly from Timiskaming subprovince to Rainy Lake, has shown that the stratigraphic succession for this subprovince may be expressed as follows:

Table of formations

Kaministikwia group (upper copper-bearing series of Logan).	(Granite intrusive.)
	Osler series.
	Sibley series.
	Animikie series.
Great unconformity.	
Basement complex:	Batholithic intrusives.
	Series based by a granite-pebble-bearing conglomerate.
Unconformity.	
	Batholithic intrusives (not positively identified in the field).
	Volcanic complex.
	Sedimentary, mica-schist assemblage.

[1] Part of the symposium on Precambrian geology.
[2] Introduced by Charles K. Leith.

Basement Complex

Throughout the subprovince there are extensively developed batholithic intrusives. These are the youngest rocks of the Basement complex which have been recognized. The granites which make up a part of the assemblage mapped as Batholithic intrusives are massive, except in the vicinity of local faults, and there is no evidence that they have been affected by regional pressure since they solidified. Around the granites there are commonly contact zones some miles in width, consisting of a great variety of simple and compound rock types, all of which, in my opinion, may be regarded as the products of the interaction of the intrusive batholith and the older intruded rock.

Figure 1.—*Contact between granitized Schist and schistose Andesite*

The locality is Arnold Lake, Rainy River district. The dip of the foliation in both rocks is about 80 degrees. If this were regarded as stratification, the lava would appear to lie above. According to an early classification, this figure would illustrate the Huronian (lava) in contact with the more highly metamorphosed Laurentian (gneiss).

Where the old schists have been semigranitized by pervasive agencies which have diffused more or less evenly through the rock, gneisses and migmatities occur which plainly exhibit a legacy of characteristics from the intruded rock, including its foliation. The study of such rocks where they appear to underlie the less-altered adjoining schists gives one an appreciation of Logan's early interpretations, that these Laurentian rocks were at the base of the geological column (figure 1).

The excellent work of Dr. Lawson in this subprovince gave us our

modern interpretation of these gneisses and migmatites (figure 2). By stressing their affinities with the intrusive rock rather than with the intruded rock and carefully considering the significance of all factors involved in terms of history, he displaced the Laurentian from the base of the geological column and gave us the term Coutchiching for that highly altered shaly series of sediments which he found to be the oldest rocks in Rainy Lake district.

The recently prepared maps[3] of the Geological Survey of Canada show that there are extensively developed zones of altered sedimentary rocks extending across the subprovince from Rainy Lake to Oba, a distance of 400 miles. This is the *mica-schist assemblage* and it embraces no lavas

FIGURE 2.—*Granite and related Rocks*

These occur at Arnold Lake as irregular-shaped, rounded masses and streamers through schistose ellipsoidal andesite. This locality is within 100 feet of that shown in figure 1. The rocks are now classified as Keewatin and later granitic intrusives.

where I have mapped it. In coming westerly from the Timiskaming subprovince, I first met this mica-schist assemblage among the batholithic intrusives near Oba, where it is certainly at the base of the local geological column. There are no other prebatholithic rocks in that locality. Elsewhere across the subprovince I have failed to find evidence

[3] G. S. C. Map No. 1697, G. S. C. Summary Report, 1926;
Map No. 1698, G. S. C. Summary Report, 1916;
Map No. 1766, G. S. C. Summary Report, 1918;
Map No. 1836, G. S. C. Summary Report, 1917;
Map No. 2069, G. S. C. Summary Report, 1924;
98A, G. S. C. Memoir 40, 1913, &c.

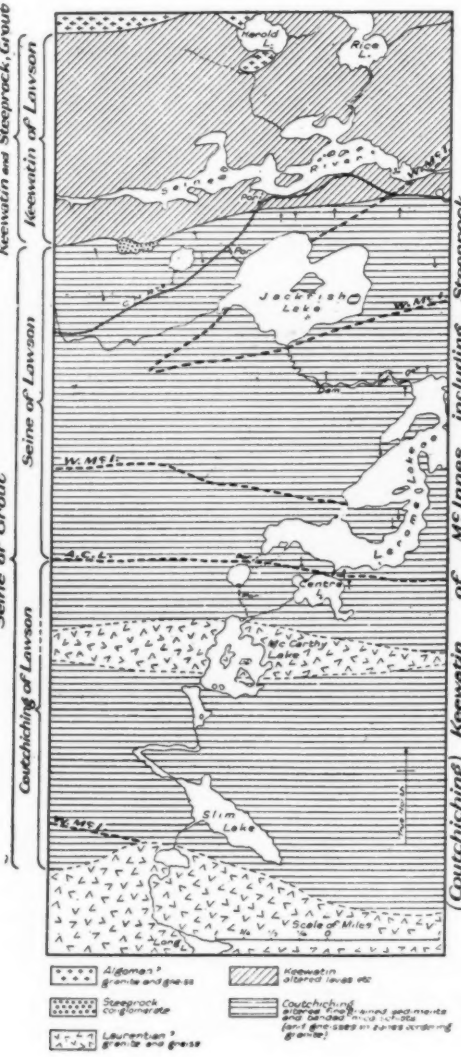

FIGURE 3.—*Geological Map along Canoe Route from Rice Lake to Long Lake.*

The various geological classifications are shown in reprint of figure 1, Transactions of the Royal Society of Canada, third series, volume XX, section 4, 1926, page 40.

that the rocks of this subdivision overlie any other subdivision of the Basement complex.

Coming to Steeprock Lake, the field mapping has been of a more detailed character than farther east, and, thanks to the contributions of Grout, we have been able to concentrate attention on a definable contact between the mica-schist series and the adjoining surficially formed rocks. We find, as reported in the Transactions of the Royal Society of Canada (figure 3), that the Coutchiching series is here more extensive than indicated by Lawson's work of 1911, and that at the precise contact with the Keewatin the tops of the Coutchiching beds are *toward* the Keewatin. Similar determinations were made last summer on Rainy Lake, both in

FIGURE 4.—*Granite and related Rocks*

These rocks occur on the north shore of Review Island, Minnesota, as irregular-shaped rounded masses and dikelike intrusions through Keewatin greenstone. Prior to 1926 this complex was mapped by Dr. F. F. Grout as conglomerate and correlated with other conglomerate of Lower-Middle Huronian age in Minnesota.

Ontario and Minnesota. The Coutchiching series embraces the oldest rocks of these localities; above comes the Keewatin. Above the Keewatin comes the Steeprock series, based by a granite-pebble-bearing conglomerate. The basal conglomerates of the Steeprock and Lawson's Seine series have been correlated, and the present opinion is that the Seine series of Lawson does not exist as an entity distinct from the Steeprock series.

Very significant results have come from the consideration of granite-pebble-bearing conglomerates in the Rainy Lake region. For instance,

such a conglomerate was mapped by a Minnesota geologist[4] along the position of a granite-greenstone contact on Grassy and Review islands, in Rainy Lake, Minnesota. Figures 4 and 5 are actual pictures of it. It was correlated with other conglomerates of Lower-Middle Huronian age,

FIGURE 5.—*Irregular-shaped Blocks of Hornblende-chlorite Schist in a Matrix of intrusive Granite*

They occur on the north shore of Grassy Island, Minnesota. Prior to 1926 this complex was mapped and otherwise treated by Dr. F. F. Grout as conglomerate of Lower-Middle Huronian age. This and the subject of figure 4, and other rocks of different appearance which Grout formerly regarded as the same conglomerate member in this locality, are all, in Tanton's opinion, different in origin from the basal conglomerate of Lawson's Seine series.

and a plausible structural interpretation was submitted to a meeting of this Society two years ago as evidence that the Coutchiching series of

[4] F. F. Grout: Bull. Geol. Soc. Am., vol. 36, 1925, p. 359.

Lawson as developed across the international boundary is unconformably above the Keewatin.

Dr. F. F. Grout discovered last summer, while I was with him, that this reported conglomerate was an example of erroneous lithological determination. It is now evident that there is no real conglomerate at the site of this reported occurrence. Grout's section for this locality, as published, requires some modification.

I shall not refer to all the revisions of geological mapping that I would consider expedient as a result of the studies which I made with Dr. Grout on the southeastern portion of Rainy Lake, in Minnesota, last summer. Suffice it to say that Dr. Grout and myself are in complete agreement

FIGURE 6.—*Schistose and highly folded granite-pebble-bearing Conglomerate from Atikokan, Ontario*

This is the basal member of Seine series of Lawson. Tanton correlates this with basal conglomerate of Steeprock series.

on all matters which either one of us would call obvious field facts. We did not know at the time Grout left the field last summer of any satisfactory field evidence to indicate that Lawson's Coutchiching was stratigraphically above the Keewatin in Minnesota. The case for the early structural interpretation of Grout failed to prove convincing; alternatives were recognized point by point, 1, 2, 3, 4, as the examination proceeded. To quote his own summary of the results:

"There remains, then, only to appeal to (5). On Morton island Grout and Tanton agree as to the map, the findings, and the probable folded formation. Two or three interpretations are still possible."

These interpretations refer to an indefinitely located contact concealed by a water body one-fourth mile wide, and there is a question as to whether there is an odd or an even number of reversals in the attitude of closely folded strata between the exposed beds on the island and the submerged contact. The argument against Lawson's interpretation of the stratigraphic position of the Coutchiching here is that Dr. Grout believes that the number is even.

In Minnesota, as elsewhere through the subprovince, there are folded prebatholithic rocks younger than the Keewatin (figure 6). I have

FIGURE 7.—*Animikie Sediments*

These sediments lie on the smoothed floor of Keewatin schists and granitic intrusives on the shore of Lake Superior near Schreiber, Ontario. The granite of this locality has been mapped as Algoman.

failed to find evidence for correlating any of these rocks with the Cobalt or Bruce series of the Timiskaming subprovince.

PRE-ANIMIKIE PALEOPLAIN

In Thunder Bay district the Kaministikwia group of rocks lies on an extensive paleoplain (figure 7), which appears to be the counterpart of the eastern paleoplain on which the Cobalt series was laid. The brilliantly reflecting feldspars of the crystalline rocks in the smoothed floor on which the Animikie sediments were laid and the general lack of residual weathering products are interpreted as evidence of glacial scouring. This record of glaciation, in my opinion, may be the stratigraphic correlative of the tillite which occurs in the Cobalt series.

KAMINISTIKWIA GROUP

The Kaministikwia group has been found to consist of three series. From oldest to youngest, these are the Animikie, Sibley, and Osler series. These series are intimately related areally and they visibly overlie one

FIGURE 8.—*Contact between Animikie and overlying Sibley Series*

The locality is south of Surprise Lake, east of Thunder Cape. The broad features which distinguish the Sibley series are red, fine-textured sediments and white sandstones. At some localities the precise position of the contact is marked by conglomerate with pebbles of Animikie rocks. At this locality the basal conglomerate is part of a sandstone layer a few inches thick. Red beds and white sandstone appear in the succession a few feet or inches respectively below the conglomerate. Local folding has affected competent and incompetent beds differently, but this is not to be interpreted as an angular unconformity. Gray beds below, red beds above.

another successively. Each series is made up of a basal conglomerate and a peculiar assemblage of lavas, tuffs (or fragmental lava material of local derivation), chemical precipitates, and clastic rocks. The rocks of

all the series are nearly flat-lying, with a gentle regional dip toward Lake Superior, and have been disturbed by local folding and faulting. There is no regional angular discordance between the series. Metamorphic phenomena occurs in an equivalent degree in all the series. The rocks of each series, considered collectively, are distinctive and the bedded

FIGURE 9.—*Basal Conglomerate of Osler Series*

The locality is Osler Bay, Edward Island, about 15 miles east of Thunder Cape. This conglomerate has the same significance for purposes of rock group subdivision as has the conglomerate which occurs locally in the Sibley series just above the Animikie. The position and field relations of the Osler conglomerate indicate that it is at the base of the Keweenaw group, first named by Hunt in 1873. The term Keweenawan, as applied in Thunder Bay district, in the U. S. Geological Survey Monograph 52, does not correspond with the early usage, nor does it embrace all of the Upper Copper-bearing series. The Osler series embraces the lowest series of the Keweenaw "group" of Hunt; whether or not it embraces the entire "group" depends on the interpretation of a thick conglomerate well up among the lavas or some other feature of the record which would admit of recognition as a basis for subdivision in the principal areas where the Keweenaw "group" is developed.

rocks appear to have been deposited in shallower water in each successively higher series.

Originally the Animikie was differentiated from the rest of the Kaministikwia by Hunt[5] on the basis of a lithological difference without reference to a basal conglomerate.

Subsequently it was found that a basal conglomerate occurs locally at the horizon where the gray sediments are succeeded by the red. It is now known that the basal conglomerate is locally absent, and that the change from gray to red shaly rocks occurs below the conglomerate horizon (figure 8). Generally there is no angular discordance between the Animikie and overlying Sibley series. There are apparent exceptions

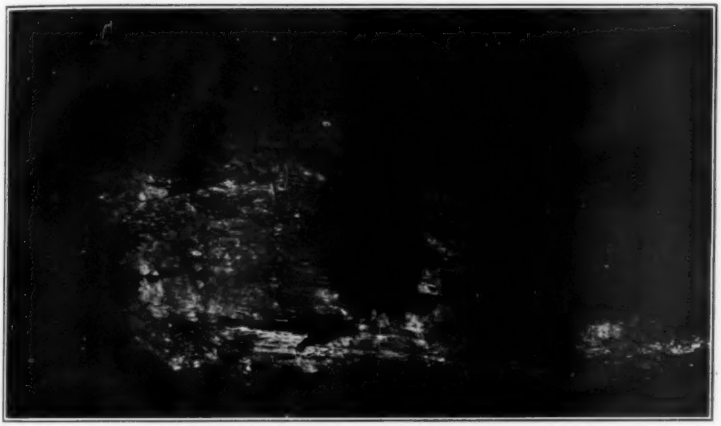

FIGURE 10.—*Copper-bearing amygdaloidal Lava*

The lava lies over stratified, fine-grained, red, volcanic debris and cross-bedded red and white quartz sandstone of the Osler series, Edward Island.

where local crumplings have affected the strata of different degrees of competence in different ways. The presence of the basal conglomerate in the Sibley series and the extension of the Sibley series east of Loon, beyond the margin of the Animikie on to the old basement, is interpreted as due to local faulting and the extension of the basin of deposition. The Animikie series is thin near Loon, and when traced northerly under the Sibley series it ceases abruptly at a recognizable fault. The base of the Sibley series does not bevel across the lower members of the Animikie.

The contact between the Sibley and the overlying Osler series is marked by a basal conglomerate (figure 9), at least 12 feet thick, which is well

[5] Trans. Am. Inst. Min. Eng., vol. 1, 1873, p. 339.

exposed at Osler Bay, on Edward Island, and in the cliffs along the northern side of Saint Ignace Island and the islands east of it—that is, through a distance of over 70 miles. This conglomerate has been ignored in previously proposed classifications, but in my opinion it has a significance similar to the lower conglomerate at the base of the Sibley series. Its pebbles are diversified and consist of sandstones and lavas presumably derived from the Sibley series; also a red quartz feldspar porphyry and rock representative of all the older known rocks of the region. The pebbles are well rounded. No regional angular discordance has been recognized between the rocks above and below the conglomerate, and the rocks of both series, as mapped close to the conglomerate, dip at very

FIGURE 11.—*Diabase Dike cutting Osler Sediments and overlying Lavas, Edward Island*

The numerous intrusives of this character might be dated as Kaministikwan or post-Osler. They can not properly be dated as Keweenawan so long as the practice continues of applying this term to a subdivision of the Upper Copper-bearing series, whether in the sense originally proposed by Hunt or in accordance with the usage which extends the Keweenawan over two of the three subdivisions recognized by Hunt, namely, Keweenaw-Nipigon. On some maps these intrusives are shown as post-Keweenawan.

low angles. The quartz sandstones and intermixed and interlayered red, tuffaceous, shaly rocks above the conglomerate characteristically show cross-bedding and ripple-marks. The lithologically similar rocks which occur near by, below the conglomerate, are evenly bedded and are commonly intimately associated with limestone.

The sediments in the lower part of the Osler series are 40 feet thick on Edward Island and possibly 200 feet thick on Saint Ignace Island. Their volume is approximately the same as the greatest development of

Lower Keweenawan found elsewhere in the Lake Superior region. They are overlain (figure 10) by a thick assemblage of lava flows and interstratified fine and coarse fragmental material which has been derived from the lavas.

On Saint Ignace and Simpson islands there is a large mass of intrusive porphyritic granite which is characterized by pink, zonally banded feldspars. On Simpson Island it is known to have the form of a sill. The basic lavas and other strata adjacent to it show no marked structural disturbance. The intrusive granite appears on the map to be areally continuous with quartz-feldspar porphyry farther west, which may be either an intrusive or an extrusive, and this in turn appears to be continuous with an amygdaloidal quartz porphyry found as far west as Agate Point.

The youngest consolidated rocks of the Kaministikwia group are diabase dikes (figure 11).

Discussion

Dr. F. F. Grout pointed out that the statements in this paper do not fairly present the basis for his structural interpretation of the Coutchiching on Rainy Lake. His structural section, presented to this Society two years ago, represents his present inferences regarding the stratigraphic succession and the structure of the rocks. In fact, an alternative structure section sketched in the field by Tanton shows more errors than any before sketched. He conceded that the supposed conglomerate which he had reported two years ago as occurring on the north shore of Grassy Island, and which Tanton had figured, is not a conglomerate, but is a rock formed as a result of a granite intrusion; but this admission does not at all remove the basis for Grout's structural interpretation. A supposed conglomerate just west of Grassy Narrows Grout regards as the westerly extension of the Grassy Island "conglomerate." Tanton regards this as a granitized water-worn pyroclastic of Keewatin age, correctly mapped by Lawson as Keewatin. Grout offered to refer it to any committee of impartial observers to determine the character of this rock and compare it with the basal conglomerate of Lawson's Seine series on Neil Point and elsewhere in that vicinity.[6]

C. K. Leith: What is the significance of the term Kaministikwia?

[6] Careful work was done by a Minnesota Geological Survey party in the summer of 1927 to determine whether Doctor Tanton's evidences of Coutchiching on Rainy Lake make it desirable to retain the name for any rocks in Minnesota. At the type locality for the Coutchiching formation and at various localities near by, the evidence furnished by detailed mapping is all against the occurrence of any sediments older than the greenstone. No Coutchiching rocks are therefore recognized in Minnesota—Frank F. Grout.

T. L. TANTON: Kaministikwia is a name derived from an important geographical feature in Thunder Bay district and suggested in this paper as a suitable name for the group of rocks formerly named the Upper Copper-bearing series by W. E. Logan. There is now no other simple term which is commonly used with this significance. The name as used in the paper is that of a group of rocks and not a time term.

DISCUSSION IN AFTERNOON SESSION

C. K. LEITH (chairman) invited Mr. Tanton to open the general discussion.

T. L. TANTON: The stratigraphic succession of the northern subprovince of the Lake Superior region was restated. It was explained that the principal significance of this contribution, in the author's opinion, lay in the fact that all time terms were avoided, and that the statement or discussion arising from it would be clearly understood as referring to rocks or other *tangible* phenomena of significance to geologists. Terms such as Keewatin and Huronian are commonly applied both to rocks and divisions of geological time. These two things are not the same; one is concrete, the other abstract; but, so long as the same term is used for both, it is difficult to clearly differentiate the two mental concepts or to discuss those tangible problems which admit of or invite solution by field studies without being entangled by considerations of an abstract nature relating to time classification.

A somewhat detailed statement regarding field observations was made with reference to each subdivision of the stratigraphic column. Present information indicates that there is a very extensive development of the mica-schist assemblage in this subprovince. Where detailed studies have been made, evidence has been found that these rocks are at the base of the local geological column. Rocks mapped as Coutchiching by Lawson on Rainy Lake form part of this assemblage. Tanton's opinion regarding the distribution of the sediments which might be grouped as Coutchiching near Steeprock Lake is more nearly in agreement with that of Grout than of Lawson. The mica-schist assemblage does not include lavas; this generalization adequately defines the method of determining the boundary with the volcanic complex (or Keewatin of Rainy Lake) in the field.

It is not known whether a great lapse of unrecorded time occurred between Coutchiching and Keewatin deposition or not. The evidence of the rocks is that the geological processes predominating during the time of the formation of these two rock assemblages were very different.

The volcanic complex embraces a great variety of rock types in addi-

tion to the characteristic pillow lavas, including stratified fragmental rocks of various textures and banded iron formation.

Intimately associated with this complex, there is in each area that has been mapped a granite-pebble-bearing conglomerate and younger sediments, a slaty or otherwise distinctive phase of iron formation, and locally (as at Steeprock Lake) pillow lavas and limestone. These rocks are highly folded and are locally known and elsewhere inferred to be older than certain extensively developed granite intrusives near them. These rocks, which are differentiated from the volcanic complex, have been encountered or mapped by Tanton, in crossing the subprovinces, under the following designations: Pre-Huronian, Timiskaming, Windigokan, Lower Huronian, Steeprock, Seine, Lower-Middle Huronian. Each of these series is based by the oldest granite-pebble-bearing conglomerate of the local stratigraphic column, and all are known or inferred to be older than the great paleoplains under the Animikie and Cobalt series respectively. No two such series have as yet been described as coming in contact with one another. There is no known reason why all may not be correlated with one another.

The unconformity between the Animikie and the older rocks is by far the greatest and most striking unconformity recognized in the subprovince.

Recent studies of the Kaministikwia group have resulted in the recognition of copper-bearing amygdaloidal lava within the Animikie; also stratified volcanic debris and red beds, such as characterize the immediately overlying rocks. The conglomerate which has recently come to be regarded as of significance in defining the top of the Animikie is locally absent. The Animikie strata lie in nearly horizontal attitude, are not highly metamorphosed, and in general present such close affinities with the overlying rocks that they are to be regarded as part of the major group. This major group was long known as the Upper Copper-bearing series. In 1873 three subdivisions were named by Hunt: Animikie, Nipigon, and Keweenaw. A study of the literature and a familiarity with the rocks in the field indicates that these divisions probably are the same as those now called Animikie, Sibley, and Osler, and that the division between the latter two in each case is not that indicated by the description of the boundary between the Lower and Middle Keweenawan of U. S. Geological Survey Monograph 52. The base of the Osler series is marked by an extensively developed conglomerate with well rounded pebbles of divers rocks.

The field phenomena for subdividing the Sibley and Osler series is essentially equivalent to that found at the Animikie-Sibley contact.

The conglomerates which occur interstratified with the great lava assemblage of the Osler series appear to be of local derivation, and they appear to have no more significance for purposes of classification than those which have been described in the Middle Keweenawan rocks of Michigan. The time terms, Animikean, Nipigon, and Keweenawan, are not now generally recognized as embracing the time during which the rocks formed which Hunt in 1873 named Animikie, Nipigon, and Keweenaw respectively. To give expression to the interpretation of the rocks and to escape the confusion that might result from a use of time terms which have had more than one significance, the terms introduced by the author appear to be necessary.

Subsequently, geological time terms were set opposite the formational terms that had been used in discussing Tanton's paper, and the scope of the discussion was broadened.

It would be a simple matter to apply in this subprovince a Precambrian time scale which is in use in the adjacent subprovince to the east. There, W. H. Collins uses only two major time terms, Huronian and pre-Huronian. The application of this terminology depends in part on the recognition of the major unconformity that immediately underlies the Cobalt series or other formations closely related in time. In the northern subprovince of the Lake Superior region the only unconformity of this character which has been recognized is that beneath the Animikie, and hence the pre-Animikie rocks may be assigned to pre-Huronian age.

In the adjacent subprovince to the east the Whitewater series of Collins and all other surficially formed rocks known or inferred to be younger than the Cobalt series have not been found in contact with the latter. It is not known whether a great unconformity occurs in the succession just above the Cobalt or not. Admitting that there may be, it is the practice to break the bracket embracing the record of Huronian time at the position just above the Cobalt, and thus to permit of reference to the time succeeding the Cobalt as Huronian (?). Until further information is obtained or until a wider agreement as to interpretation is reached, one might employ the terms Huronian and Huronian (?) so that recognition of a problem can be simply indicated on maps by a break in a bracket, and that where no contribution is being made toward the elucidation of the problem and no special recognition of it required the single term Huronian can be employed.

Huronian time, according to Logan's definition, extends upward to the base of the Paleozoic. It so happens that all the rocks which are shown as of Huronian (?) age by Collins in the subprovince east of

Lake Superior were regarded as of Paleozoic age by Logan. They are now generally regarded as pre-Paleozoic.

Accepting Logan's definition of Huronian time, the rocks of the Kaministikwia group in the northern subprovince of the Lake Superior region might have been assigned to the Huronian as soon as it was found desirable to classify them beneath the Paleozoic. This has not been done. They might now be assigned to a Huronian (?) age, thus (1) following the conventional agreement that they are pre-Paleozoic, (2) conceding that they are not known to be assignable to a major time division younger than and different from that in which the Cobalt series occurs with any more reason than might be adduced in the Sudbury district, (3) indicating that no important unconformity is recognized within the Kaministikwia group, and (4) admitting of a usage analogous with that in the subprovince east of Lake Superior.

If it were known or generally agreed that there is on the south shore evidence of a great unconformity at or below the base of rocks correlated with the Animikie and above those rocks correlated with the Huronian of the type locality, the term Huronian-query might suitably be replaced by a time term corresponding to the formational term Kaministikwia.

R. C. Allen stated that there is a widespread granite intrusive and an important unconformity just beneath the Copps series in Michigan. The Copps series is the equivalent of the slate portion of the Animikie. The granite is intrusive into Huronian rocks. The term Algoman of Lawson could be applied to this granite.

C. K. Leith: The dominating feature of Mr. Tanton's classification is the great unconformity at the base of the Animikie, which is indeed very striking. As a corollary, he minimizes the unconformity below the Knife Lake slates and their equivalents by including them in his basement complex, together with Keewatin greenstones and Laurentian granites. All the succession and structural relations, both igneous and sedimentary, worked out by the U. S. Geological Survey for the Vermilion district of Minnesota, for instance, are by inference blanketed by the term "Basement complex." Likewise, the unconformity between the Animikie and the overlying Keweenawan series is practically eliminated and the two series are grouped together as one. The classification as a whole reflects obvious contrasts between little deformed and little metamorphosed series above this great unconformity and much folded and metamorphosed series below it, regardless of the number of series and the complexity of their relations. It puts the entire emphasis on a single batholithic intrusion preceding the Animikie and ignores an earlier batholithic intrusion preceding the Knife Lake sedimentation.

Any attempt to extend such a classification to the south shore of Lake Superior would give even a more distorted perspective, because there Tanton's "Basement complex," including as it does everything below Animikie, would have to include the Lower Marquette and Lower Menominee series. The great unconformity at the base of the Animikie then passes between two Huronian series almost concordant in attitude. Likewise it would minimize the definite unconformity between the Animikie and the overlying Keweenawan. Still further, the Animikie in parts of the southern subprovince is itself folded and metamorphosed by batholithic intrusion, and if one were to classify simply on the basis of these features it should be itself pushed down into the Basement complex.

In short, Mr. Tanton's classification seems to overemphasize a single unconformity—one long ago called the "Eparchean interval" by Lawson. It is my belief that this term has delayed an understanding of general Lake Superior correlation by its implication that an unconformity which is locally conspicuous should be made the basis for general classification. Every unconformity in the Precambrian of Lake Superior changes its aspect in various parts of the region. Neither Mr. Tanton nor any one else can show that this unconformity represents any more or less time than unconformities above or below, even though in his subprovince it is the most conspicuous one. On the south shore similar emphasis on the most conspicuous unconformity *there* shown has put the Basement complex considerably farther down, but for some years I have been getting away from the notion that we are warranted in tying too closely to any particular unconformity as a basis for classification except for very local purposes.

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LAKE SUPERIOR PRECAMBRIAN[1]

BY C. K. LEITH

(Read before the Society December 27, 1926)

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ORIGIN OF IRON ORES

Recent studies of the origin of the iron formations of the Lake Superior region, including those of Collins, Gruner, Hawley, and others yet unpublished, tend, on the whole, to show that the iron formations are inorganic chemical precipitates, that organic agencies have played a relatively small part, that volcanic sources have made notable contributions, and that normal processes of weathering have likewise been effective. All of these factors have been previously recognized, but now they can be more specifically identified. The studies of secondary concentration of the iron ores themselves have not changed earlier concepts of the processes.

CORRELATIONS

It has long been agreed that the Animikie of the north shore and the Gogebic iron-bearing series ("Upper Huronian") are the same. In the past this has been correlated with the uppermost of the Huronian series in the remaining districts of the south shore, but it now appears possible that it should be correlated with the Middle Huronian series, containing the Negaunee iron formation. This new point of view is based primarily on an unconformity observed locally above the Gogebic iron formation and below the slates (Tylers and Copps) previously included with this series, making it possible to correlate the Copps slate with the Upper

[1] Extended abstract, forming part of the symposium on Precambrian geology.

Huronian of the other districts. In two or three other places in Michigan local conglomerates have been noted at what is supposed to be the same horizon. The evidence is yet far from conclusive, but so far as it goes it points to the new correlation indicated. If it is true, there ought to be an unconformity between the Mesabi iron-bearing formation and the overlying Virginia slates, previously regarded as conformable and belonging to the Animikie series. Minor evidences of unconformity have been found on the Mesabi Range, but they are extremely fragmentary, and the burden of proof yet rests on any one seeking to prove it.

If the new correlation of the Lake Superior iron formations is ultimately established, it raises some interesting questions. What shall we call Animikie—the upper slate series above the iron formation, or the iron formation itself, with its underlying quartzite, which has ordinarily been regarded as the most characteristic feature of the Animikie? The application of the terms Upper, Middle, and Lower Huronian will have to be changed, "Upper" being applied to the slate above the Mesabi iron formation, "Middle" to the Mesabi iron formation and its equivalents, and "Lower" to the Knife Lake slates and to the lower dolomite-quartzite series of the Marquette and Menominee districts.

Beneath the Mesabi iron-bearing series of the north shore and above the Keewatin and Laurentian complex comes the Knife Lake series. On the south shore, in the same relative position beneath the equivalent of the Mesabi series, comes the Lower Gogebic, Lower Marquette, and Lower Menominee series. These series contrast with the Knife Lake series in being well assorted marine sediments, whereas the Knife Lake series is an ill assorted mud-sand-conglomerate formation of presumably continental origin. In Monograph 52 of the United States Geological Survey it was suggested that the former might be the marine equivalent of the latter, but, as there suggested, the Knife Lake series might very well be older than the Lower Marquette or Lower Menominee, even though no trace of it has yet been found in the pre-Huronian rocks of those districts. The fact that the Knife Lake series as a whole has been much more closely folded and metamorphosed as a result of granitic intrusions has little bearing on the question, because this aspect depends principally on local batholithic intrusion, and in parts of the southern subprovince later sediments show the same features, due to plutonic intrusions.

The Plutonic Granite Intrusions

Understanding of the possibilities of Lake Superior correlation must start with recognition of at least three periods of plutonic granitic in-

trusion. A good deal of confusion has been introduced into discussions of correlation by ignoring one or more of these. On the south shore there are granitic batholiths of at least two ages—one preceding the Huronian series (Laurentian) and another one following (Killarnean), presumably of Keweenawan age. There is a possibility of a third (Presque Isle) following the Gogebic iron formation and preceding the Copps or the Tylers slate, but the evidence for this is very local and this period does not seem to have been characterzied by the great mountain-making disturbances which are characteristic of the others. This intrusion can not be called Algoman or Giants Range because it cuts rather than precedes the Animikie iron formation.

On the north shore of Lake Superior also there are two great periods—one (Laurentian) preceding the Knife Lake deposition and another (Giants Range or Algoman) following it, but preceding the deposition of the Mesabi or Animikie series. Later batholitic intrusion into the Upper Huronian and possibly Keweenawan series, so conspicuous south of the lake, is absent to the north. If later intrusion had occurred there, geologists would have put much less emphasis on the so-called "Eparchean interval" at the base of the Animikie series.

The earliest granite of the north shore has been correlated with the earliest of the south shore and called Laurentian by the United States Geological Survey, but there is no decisive proof that the Algoman of the north shore may not be equivalent to the earlier granite of the south shore. This would be in line with the contention of the Canadian geologists, that all pre-Algoman rocks are basement complex. It would be difficult, however, on this view to account in the south for the absence of the earlier granites, and the Knife Lake slates, and for the similarity of the relations to greenstones, supposed to be Keewatin.

Batholiths usually cause structural disturbance and metamorphism in the intruded series, in contrast to the series laid down above them, and therefore the unconformities in the vicinity are striking. Where the unconformities are traced away from these intrusions they become much less obvious, though they probably represent fully as great a lapse of time.

East Shore of Lake Superior

On the east shore of Lake Superior satisfactory progress is now being made in the detailed mapping of the Precambrian, leading to the hope that this region (which includes the Original Huronian) may be soon fitted into the picture. The present view of the Canadian Geological Survey, as indicated on its progress map, is that the Huronian series is

later than the great series of sediments (Doré) represented in the Michipicoten district, but the two districts are separated by a hundred miles or more of little known granite, with minor troughs of sediment and greenstone, and the correlation is far from certain. It is Collins' view that this granite underlies the Huronian series and is the same granite which intrudes the Michipicoten series of sediments, though he also recognizes in the Michipicoten district the existence of an earlier granite. The results of this study will be highly significant, because the United States geologists have thought the Michipicoten sediments as possibly equivalent to the Knife Lake, and if they can be demonstrated to be definitely below the Huronian this will largely settle the moot question of the relative position of the Knife Lake and the Lower Marquette series. It is interesting to note that three periods of granitic intrusion are now assumed by the Canadian Geological Survey: the post-Huronian (Killarnean), pre-Huronian, and pre-Dorian.

There is a notable tendency among geologists taking part in the field-work now going forward in the Lake Superior region to abstain from generalizations about the region as a whole, and to confine their attention for the time being to the attempt to agree on basic facts. There have been two conferences of geologists concerned at Madison, and a third is now planned for the near future.

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KILLARNEY GNEISSES AND MIGMATITES[1]

BY TERENCE T. QUIRKE

(Read before the Geological Society December 27, 1926)

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INTRODUCTION

The Huronian sediments, which stretch almost unbroken from the western end of Lake Superior to a line between Killarney and Lake Temiskaming, end abruptly against an area of gneisses.

This area of gneisses, previously thought to be of pre-Huronian age, is now known to be composed in part of rocks younger than the Huronian sediments and known as the Killarney intrusives, in part of remnants of conglomerate, quartzite, and calcareous amphibolite belonging to the Bruce series, and in part of highly metamorphosed gneisses of granitoid composition, also of Huronian age.[2]

These rocks display certain characteristics of regional contact metamorphism which are unusually well developed, deserving special description and discussion. They include good examples of the mixed rocks, hybrid between igneous and sedimentary rocks, called by Sederholm "migmatites."[3]

[1] Part of the symposium on Precambrian geology.
Published with the permission of the Director, Geological Survey of Canada.
[2] Cf. Bull. Geol. Soc. America, vol. 35 (1924), pp. 89-90.
[3] J. J. Sederholm: Commission Geologique de Finlande, Bull. 58, 1923, part 1.

The general geology of this district recently has been discussed in some detail elsewhere [4] and needs little further general description.

This paper deals with the development of the gneissic granitoids, which seem to have been derived from Huronian sediments by a sort of

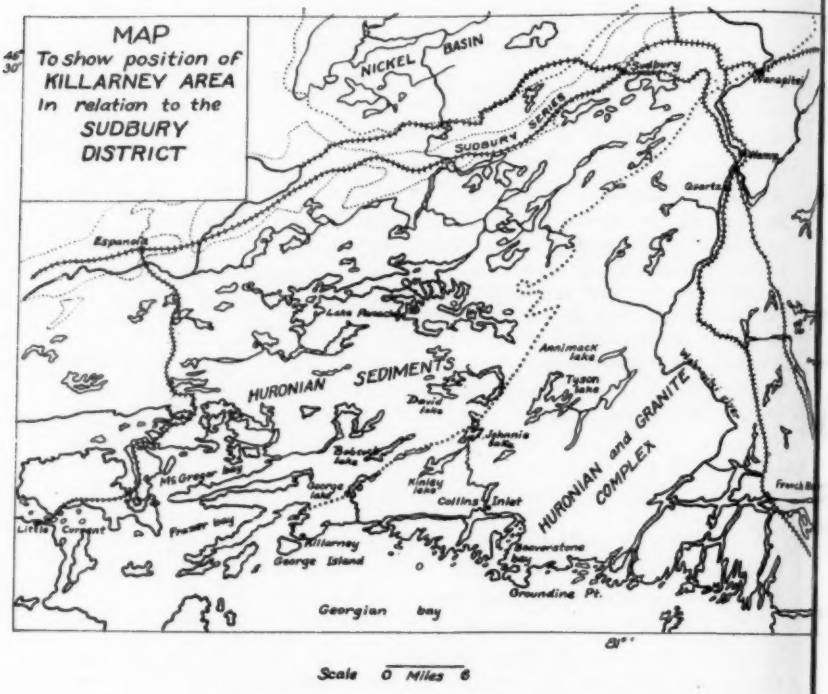


FIGURE 1.—*Map showing Killarney Area*

ultra-metasomatism,[5] as it is called by Sederholm, involving regional replacement of quartzite by feldspar on a huge scale. Hundreds of

[4] W. H. Collins: Geological Survey of Canada, Memoir 143, 1925, pp. 85-93.
T. T. Quirke: Huronian complex near Killarney, Ontario. Abstract, Bulletin of the Geological Society of America, vol. 135, 1924, pp. 89-90.
Correlation of Huronian and Grenville rocks. Journal of Geology, vol. 32, 1924, pp. 316-335.
British Association for the Advancement of Science, Journal of Scientific Transactions, Toronto, 1924, pp. 35-36.
Huronian Grenville Relations. American Journal of Science, vol. 11, 1926, pp. 165-173.

[5] J. J. Sederholm: Personal communication.
Also, cf. W. Lindgren, Bulletin Geological Society of America, vol. 36, 1925, p. 252.

square miles of banded and layered gneisses have been mapped by the present writer in the service of the Geological Survey of Canada which appear to belong to this group. Rocks profoundly affected by ultra-metasomatism seem indistinguishable megascopically from those which have developed from molten igneous intrusions, and it is suggested that this sort of ultra-metasomatism properly belongs to the group of processes ordinarily included under the term "igneous intrusion."

Geological Relations

One locality which may be considered typical of the whole area was selected for detailed study; this is the neighborhood of Killarney. Near Killarney the outcrops are particularly favorable for special study, because large areas have been scoured clean by the waters of Lake Huron and others have been polished by recent and Pleistocene ice. In addition to the physical advantages of good exposures, the area affords a sediment of simple original chemical composition, the Lorrain quartzite, which is nearly pure silica at short distances beyond the zone of replacement. Starting at a quartzite headland, 2,400 feet northeast of the east lighthouse, one may follow along the strike to a quartzite island in the shelter of the northeast point of George Island; thence one may travel across the strike down Killarney Inlet for a mile and a quarter to Le Hayes Point.

Such a traverse starts on a pale green, quartzitic schist, almost exactly like the Lorrain quartzite which is being quarried for silica a few miles to the west, on Badgeley Point. This pale green quartzite contains a considerable amount of pyrite in small aggregates, the weathering of which has given rise to a series of reddish blotches on the rocks at and near this headland. As one traces the quartzite along the strike southwestward, one observes that the quartzite has certain pale brick-red patches which have a dense, stony texture, spotted with quartz pseudophenocrysts, and that very gradually the rock changes into a dark red, quartz-feldspar-sericite gneiss, which retains the definite bedding of the original quartzite and which reverts here and there into areas of pale green quartzite. Progressively, however, such quartzite masses become smaller and appear merely as pale green strings and small granules, until quartz is recognizable only as grains in pink, feldspathic, fine-grained gneiss. At the eastern lighthouse the gneiss is coarser, with here and there square-cornered orthoclase phenocrysts one-half inch in diameter; but, as noted above, on the south side of the inlet there is a recurrence of quartzite, and farther south, along the southeast shore of George

Island, the dense texture and distinct banding of the rock is very marked, in spite of feldspathic composition and gneissic texture. Passing across the strike of the rock westward, one observes that the banding in this gneiss becomes less definite, the size of the feldspar grains grows larger, a granular rather than a dense texture generally prevails, and at Jackman's store, one mile west of the lighthouse, one sees that the rock appears to be a massive igneous rock. The rock maintains this character along the walls of the inlet farther west, but along the shore of Killarney Bay northward there is a sharp line of contact between granite on the east and quartzite on the west. This contact passes across the islands in a direction almost northeast, starting at a distance of three-fourths of a mile northeast from the west lighthouse and continuing across the mainland south of Lamorandiere Bay. Farther northeastward, along the line of contact on the mainland, there are strange alternations in the exposures from rock of massive texture to rock as well banded as the sediments themselves, although maintaining the composition of syenite. Field study of this general region has convinced the writer that the banded gneiss and the massive rocks are one and the same thing, in which he follows Barlow.[6]

Bell [7] distinguished between granite and some of the gneiss, mapping as Huronian quartzite much of the pink, well banded gneiss along the shore northeast and southwest from the northeast point of George Island. However, he did not seem to recognize similar pink gneisses to the east as of the same age, for he mapped them as Laurentian; nor did he recognize the gradation of gneisses into the granite, for he mapped granite as Laurentian and the gneisses as Huronian.

The present writer found a gradual and easily perceived change from the quartzite into the pink banded gneiss. He found also that the gradation from fine-grained, well-bedded gneiss into coarse-grained, massive syenite is equally definite, and consequently that there is an unbroken gradation from quartzite at one end to syenite and granite at the other.

This appears to be a locality where sediments have been converted *in situ* into granitic rocks. The conversion seems to have involved the replacement of large quantities of quartz by feldspar.

In addition to this regional replacement of sedimentary quartzite by feldspar, there are neighboring areas which show the more orthodox effects of igneous intrusions. Places where the granite is clearly intrusive into Huronian sediments lie about the northeastern part of Lake

[6] A. E. Barlow: Bulletin Geological Society of America, vol. 4, 1893, p. 330.
[7] R. Bell: French River Sheet, No. 135. Geological Survey of Canada, 1897.

Panache and border Balsam Lake.[8] However, along the main line of contact, the relations are extremely complicated and variable. For part of the way, roughly from Killarney Bay to Kinley Lake, the contact appears to be that of an igneous intrusion which followed along a fault-plane, cutting obliquely across the strike of the anticlinal and synclinal structures of the Huronian formations. Northeastward from Kinley Lake, however, the character of the contact seems to be different. It appears to be a gradational change from well bedded sediments on the west side into stratiform gneisses continuing the structure of the sediments on the east side. These gneisses are not uniform in type across the strike, where they appear to occupy the place where the variable Gowganda formation might be expected to have been before igneous intrusion, but they generally are uniform both across and along the strike in those places where the monotonous Lorrain quartzite seems once to have been. In few places is there any indication of the familiar lit-par-lit type of injection which is commonly responsible for a similar sort of layered appearance in the rocks about large igneous intrusions. Neither is there any indication of a parallelism between the layers and the line of contact of the granitic rocks; rather the planes and bands of gneissic structure continue the strike of the sedimentary rocks beyond the zone of transition. Consequently the granitic gneisses are concluded to be the present representatives in place of the Huronian sediments of which they are the continuation along the strike. Far within the gneissic area, to the east of this line of contact, there are other areas which are occupied apparently by plutonic masses, without any appearance of a banded structure and without any indication of being anything but igneous intrusions of what may be considered the normal type. And, bordering some of these masses and in other cases far from them, there are other areas of banded gneisses which appear to be lit-par-lit injections. This injection has been so profound in its effects, however, that the injector rock is almost precisely the same in composition as the injectee, with this general difference, that the injectee is somewhat higher in finely granular silica and lower in ferro-magnesian minerals than the injector.

In these gneisses the writer has not succeeded so far in tracing one of these supposedly lit-par-lit bands either across the strike of the country rock or into fingering or pinched out terminations, except in the following places: Between the northeastern shores of Killarney Bay and Kinley Lake there are certain masses of banded gneisses near the contact with

[8] W. H. Collins: Geol. Surv. Canada, Memoir 143, 1925, Lake Panache Map.

the sediments which appear to be separated from one another by massive zones in which there is no appearance of banding, although the separate blocks of banded gneiss have suffered no shift in position or attitude in relation one to another as a result of the invasion of the intervening granite. These intervening massive areas of granite appear to the writer to be replacements rather than bodily intrusions of new mass from some other places within the earth's crust. However, the writer feels that other workers might interpret some of these banded gneisses as of lit-par-lit type. Nevertheless, he believes the evidence is so plain in many other places, especially at Killarney, Tyson Lake, Collins Inlet, and Beaverstone Bay, that the majority would agree that great replacements of quartzitic sediments have occurred, and that the resulting rock appears to be granite.

Petrographic Descriptions

Collection of specimens

Suites of specimens were collected in 1923 in the hope that microscopic examination would yield explanations of the curious transition between quartzite and granite. On the key maps (figures 1 and 2) the geological relations of this small area are indicated, and out of a large number of specimens collected for examination twenty have been marked on the map (figure 2), fifteen of which will be described herewith. The collection is designed to show, first, the gradual change from quartzite to pink gneiss and the means by which it is accomplished; and, second, the gradation from pink gneiss into typical Killarney syenite as developed at Killarney. These thin-sections are all illustrated with photomicrographs.

The series of plates, 17 to 19, is thought to show that the pink gneiss known as Killarney granite at Killarney Inlet and on Killarney Bay has been produced by the alteration of Lorrain quartzite. This alteration, not complete in the case of any specimen so far examined, has been accomplished by metasomatism, a type of replacement, of quartzite by orthoclase, whereby a rock which was originally a sediment has been altered into the physical, chemical, and mineralogical make-up of an igneous rock.

The geological relations of this igneous rock to the east are such that it grades gradually into a pink, feldspathic gneiss of unmistakably sedimentary origin. On the west this rock has intrusive relations with Lorrain quartzite and rocks of the Bruce series, especially the Espanola formation. Specimen 7 (plate 19) was collected in a place where the rock has unmistakably intrusive contacts with the Huronian sediments.

Specimens 2, 3, 4 (plates 17 and 18) are obviously close to the sediments in their characteristics, and 6 (plate 18) appears to be typical Killarney granite. Inasmuch as specimen 5 (plate 18) is intermediate between specimens 4 and 6 (plate 18), it serves to link them all together.

The writer collected specimens across the narrow contact zone between the quartzite and the granite on the west side of the granite in order to examine the character of an abrupt transition, and to compare it with

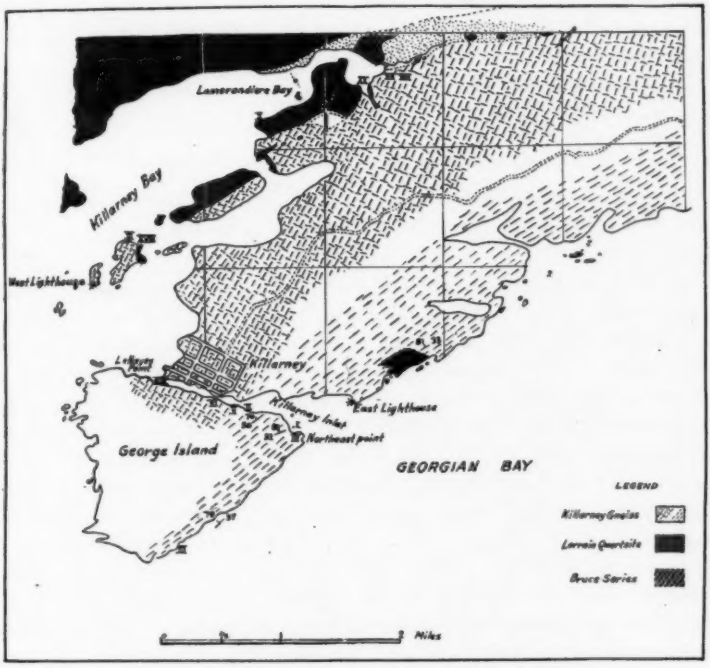


FIGURE 2.—*Geologic Map of the Killarney Area*

that of the very gradual gradation displayed on the east side. Plates 19 and 20 illustrate the petrographic character of these specimens.

Plate 21 serves to show some of the relationships between quartz and the feldspars and between one feldspar and another in the typical phases of Killarney granite.

FERROMAGNESIAN INTRODUCTIONS

In the original quartzite there is very little ferromagnesian material, and what there is in the typical Killarney granite, generally a relatively

small amount, seems to have been developed in the rock only after considerable quantities of feldspars had already come into existence. In many cases the feldspars seem to have been the hosts in which the ferromagnesian materials collected.

The late arrival of ferromagnesian minerals and earlier advent of feldspar is common in the replacement of country rock by minerals carried in magmatic emanations. In this case the most abundant invading minerals are orthoclase and oligoclase-albite, and these were first in order of arrival save for small quantities of pyrite, and were followed by amphibole, biotite, and apatite. This is quite in accord with the general procedure of magmatic emanations and in agreement with the conclusions of many others.

RELATIONS BETWEEN QUARTZ AND FELDSPAR

In every specimen examined under the microscope there is a considerable area of granular quartz which appears to be the relict or original quartzite.

In his recent memoir on the north shore of Lake Huron, Collins [9] deals in detail with the behavior of the calcareous silts of the Espanola formation under conditions of contact metamorphism. The observations of the present writer support those of Collins regarding the persistence of calcite and quartz in the Espanola formation in spite of intense contact metamorphism. When dealing with the case of the metamorphism of quartzite, Collins says: "As a rule, quartz and feldspars are about equal in amount, and together make up about two-thirds of the rock. The feldspars include plagioclase of about the composition of oligoclase, some microcline, and some orthoclase." These are the feldspars which occur in the Killarney granite just illustrated, and quartz, presumably residual from the clastic quartz of the quartzite, is found also in the Killarney granite, but in smaller proportions, much as residual quartz is found in highly metamorphosed Espanola silts.

The general relations of orthoclase to quartz, and *vice versa*, make it clear that the growth and replacement of these minerals continued over a considerable duration of time, with such diversities of relationships that at different times both quartz and orthoclase were developing at the expense of the other. Conditions such that the quartz and orthoclase were developing at the same time seem to have been common enough to provide numerous examples of a sort of microgranitic intergrowth, supposedly denoting replacement. In spite of this microgranite, which

[9] W. H. Collins: Geological Survey of Canada, Memoir 143, 1925, pp. 91-92.

might be interpreted by some readers as an indication of balanced conditions, the general trend was overwhelmingly toward the replacement of quartz by orthoclase.

CONCLUSIONS FROM PETROGRAPHIC STUDY

In general the writer concludes that there has been developed in a foundation of quartzite a crystalline, igneous rock, beginning as a fine-grained gneiss still clearly recognizable as originating in quartzite, grading into the material of the Killarney granite, and that this transformation has been accomplished by means of the introduction of feldspars, oligoclase albite, and orthoclase, the latter of which is the more stable. However, the orthoclase in many cases has changed partly or entirely into microcline, but this alteration seems to have been a later rather than an early change. During the later stages of mineralization ferromagnesian minerals, magnetite, biotite, and amphibole grew in the rock, concentrated at least at first within the feldspars. Some of the original clastic quartz seems to persist within the interstices between the large feldspars of the Killarney granite even where it invades and engulfs masses of the Espanola formation. That this is not cataclastic quartz of magmatic origin is indicated by its response to late fracturing, as illustrated in plate 19, figures 7*a* and 7*b*, and by its steady increase in quantity, without change in other appearance from smaller quantities in Killarney granite and gneisses into predominant quantities in the Lorrain quartzite, as illustrated in the series of plates, 17 to 20.

Furthermore, in the case of magmatic rocks the order of development of their mineral constituents is almost the opposite of that shown by the minerals in the Killarney granitoids. Ordinarily the earlier minerals include the ferromagnesian group, which is followed first by feldspars and last by quartz. Again, the feldspars usually interlock with one another as a result of their advanced and contemporaneous growth before the development of other minerals. In these rocks (Killarney granitoids) granular quartz seems to have been the earliest mineral and to have been replaced by widely scattered isolated feldspars, sparingly at first and later in increasing amounts. Quartz remains, now filling only interstices between large crystals of feldspar. Among the last minerals to have formed are ferromagnesian microlites within the feldspars, whereas apatite, magnetite, and amphibole usually are interstitial in plutonic rocks. Certain irregular club-shaped grains of quartz invade all other minerals, and, like the ferromagnesian microlites, may be also of high temperature origin.

Extent of Metasomatic Invasion

The feldspathization of quartzite by processes of assimilation within magmatic invasions and of metasomatism beyond the contact of intrusions has become well recorded through the great works of La Croix in the Pyrenees, of Sederholm in Finland, and of others.[10]

This process of metamorphism has been enormous in extent in the region here discussed; hundreds of square miles of sediments have been converted into banded gneisses that extend to unknown depths. The alteration of quartzites appears to be comparable in extent to the vast alterations of limestones reported by Adams and Barlow[11] in their classical treatise on the Haliburton and Bancroft areas.

Structure of Replacements

There is, however, this great difference, that whereas Adams and Barlow have to deal largely with inclusions of limestone altered to amphibolites within granite invasions, in the Killarney area we seem to find quartzites outside the borders of granitic invasions so completely altered into granitic material that they have partaken even of its physical activity, resulting in intrusive movements and actual invasion of other and less siliceous formations. This is a critical point in any argument, that sedimentary rocks have been altered into igneous rocks. Sederholm[12] quotes the case of a conglomerate with invading contacts and Smyth and Buddington[13] record flow phenomena as follows: "The appearance is as though a sedimentary gneiss were injecting, in irruptive fashion, one of its own beds." The present writer points to the environs of Lamorandiere Bay where the Killarney granite, a metasomatic replacement of Lorrain quartzite, invades the Espanola formation.

This paper supports the views of Daly,[14] announced over twenty years ago, bearing upon the secondary origin of certain granites. However, in this area there seems to be little indication that the sediments have been stoped, or swallowed up, or foundered within a granite liquid matrix. On the other hand, the original structural attitude of the sediments seems to have been preserved in spite of the profound mineralogical alteration in many places. Again, there are places where true

[10] For references consult the recent work by C. N. Fenner, idem, pp. 718, 731, 736, 738. Cf. C. H. Smith, Jr., and A. F. Buddington: New York State Museum Bull. 269, 1926, pp. 68 and 78.

[11] F. D. Adams and A. E. Barlow: Geol. Surv. of Canada, Mem. No. 6, 1910.

[12] J. J. Sederholm: Geol. Com. of Finland, Bulletin No. 58, pp. 128-137.

[13] Idem, p. 76.

[14] Reginald Daly: American Jour. Science, vol. 20, 1905, p. 185.

granites have developed, perhaps from liquid form, perhaps by a process of progressive replacement resulting in the obliteration of all traces of sedimentary structures.[15] Nevertheless, there are places also where highly crystalline quartzite remains in sharp contact with granite without any apparent reaction between rocks which in other places seem to have merged one into the other.

In the Killarney area the main masses of non-foliate granite seem to lie along great zones of displacement, with the granitized sediments and the massive rocks on the upthrow side. Perhaps these masses of granite should be called pseudo-batholiths, according to the suggestions of Kloos and Balk,[16] which are much in harmony with the ideas presented at this meeting by R. T. Chamberlin.

Conclusions

The conclusions of the present writer are greatly supported by the correlation of the general facts recognized in connection with ore deposits with theories of the invasion of igneous rocks as set forth recently in a brilliant paper by Andrews.[17]

In the region to the east of Killarney all the Huronian formations have been recognized in whole or in part, although altered profoundly by metasomatic regional metamorphism. Every sediment has naturally undergone a different course of changes, each of which is being treated in another work now in preparation; but this paper treats only of the alteration of the Lorrain quartzite. Nevertheless, it may be noted here that the end product of the alteration of all the sediments of the Huronian series, so far studied, seems to approach a common type, a granitic gneiss low in dark minerals.

The means by which such changes may have been brought about are not known. No satisfactory physical-chemical explanations seem available. There appear to be no pegmatitic feeders penetrating the gneisses near Killarney, as the only veins present are numerous, very thin veins of quartz, free of feldspar. There is no indication of an interleaving of granitic bands with less granitic bands which might represent intrusions and the original country rock. The transfer of material appears to have been accomplished without the usual mechanical details.

In the familiar case of replacement ore deposits, one accepts without much comment the distribution of pyrite throughout the country rock,

[15] Cf. C. N. Fenner: Journ. of Geology, vol. 22 (1914), pp. 692-702.
[16] Robert Balk: Bull. Geol. Soc. Amer., vol. 36, 1925, p. 689.
Cf., also R. T. Chamberlin: Jour. Geol., vol. 33, 1925, p. 792.
[17] E. C. Andrews: Econ. Geology, vol. 21, 1925, pp. 81-89.

although the physical chemistry by which pyrite is able to replace the minerals of a granite is inexplicable. In the case of the Rio Tinto deposits, as in many others, large volumes of igneous rock have been replaced, leaving no hint as to their present whereabouts. Pyrite can scarcely be considered a major constituent in igneous rock, nevertheless it has in many places emigrated from place to place in large quantities through a presumably solid country rock. Is it any more surprising that a major constituent like feldspar should display a mobility equal to that of pyrite, or that the potassium aluminum silicate should be chemically as active as iron sulphide in replacing quartz?

At this time the writer ventures to express the following opinions: In places where liquid masses were intruded from greater depths toward the upper part of the crust, replacement was negligible, and sharp contacts between granite and quartzite resulted; but deeper in the crust igneous intrusion was either anteceded or usurped by enormous metasomatism, whereby the rocks at great depths (in this region faulting has led to the exposure of rocks which were probably over 5 miles beneath the surface at the time of metamorphism) were so profoundly altered, through soaking with magmatic emanations, that their composition and structure were notably altered. After thrust-faulting erosion seems to have exposed the structure of rocks previously deep within the region of rock-flow, a structure which is scarcely to be distinguished from magmatic flow.

As Sederholm [18] says: "To me, regional metamorphism and plutonic contact metamorphism are, in many cases, synonymous processes"; so it may be that profound rock-flow and metamorphism may be accomplished by the means of metasomatic replacement,[19] or of "idiomolecular transfers," as T. C. Chamberlin,[20] expresses a similar process, and it may ultimately proceed on a vast scale to the same results as igneous intrusion.

Perhaps other granitoid masses have come into existence by a similar regional replacement of clastic sediments by feldspar within the sedimentary crust of the earth. This idea seems at least as probable as that granite batholiths have arisen from still greater depths, deriving their siliceous and feldspathic composition from hitherto-unexplained reservoirs in a zone otherwise supposedly basic. Furthermore, this suggestion helps to explain the structure of gneisses apparently accordant with

[18] J. J. Sederholm: Bulletin of the Geological Commission of Finland, No. 48 (1916), p. 139.

[19] W. Lindgren: Bull. Geol. Soc. Amer., vol. 36, 1925, p. 252.

[20] T. C. Chamberlin: Journal of Geology, vol. 34, 1926, p. 15.

that of neighboring old sediments in spite of enormous granitization—a condition which certainly does not prevail after the transgressive and disrupting results of another type of igneous intrusions.

This study fails to add anything to our ideas as to the fundamental cause of the energy, physical and chemical, which results in igneous intrusion, nor does it attempt to account for the origin of the feldspar. It reports geological relationships not commonly evident in areas of granite intrusion. Aside from the matter of bare record, the paper is contributed for the purpose of inquiring into our concepts of what igneous intrusions are, of the means or stages by which they come into the geological relations in which they now are found, and of the class of very different sort of phenomena which are grouped together as igneous intrusions.

Explanation of Plates

Plate 17.—*Micrographs of Lorrain Quartzite and Gneiss*

Specimen 1.—*Micrograph of Quartzite.* × 40

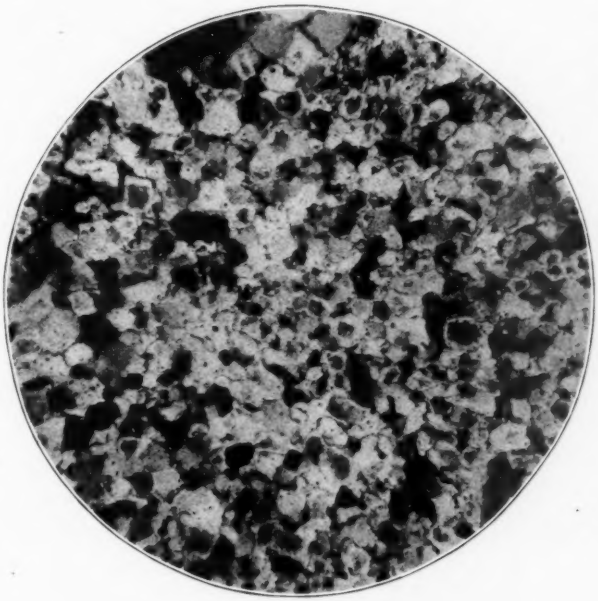
Locality, near northeast corner of George Island.

Pale green quartzite of glassy appearance composed almost exclusively of quartz, spotted with pyrite. The size of grain in different specimens changes considerably from coarser than that shown in the photograph to very much finer. However, the specimen illustrated seems to be representative of the quartzite.

Specimen 2.—*Micrograph of Gneiss.* × 40

One-half mile west of number 1.

Well-banded, fine-grained, pink gneiss collected at the Blarney Stone. This rock contains a considerable quantity of dark minerals, chiefly biotite and amphibole, with a background occupied by fine grains of quartz, but spotted with large, irregularly shaped feldspars. The feldspars show areas of vermicular quartz, with the result that it looks as if some of the quartz is later or else contemporaneous with the feldspar. However, the accompanying plate shows a feldspar growth with amœboid arms penetrating the clastic quartz groundmass of the rocks in unmistakably invading shape.



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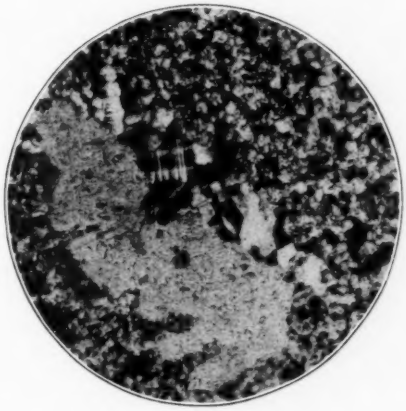
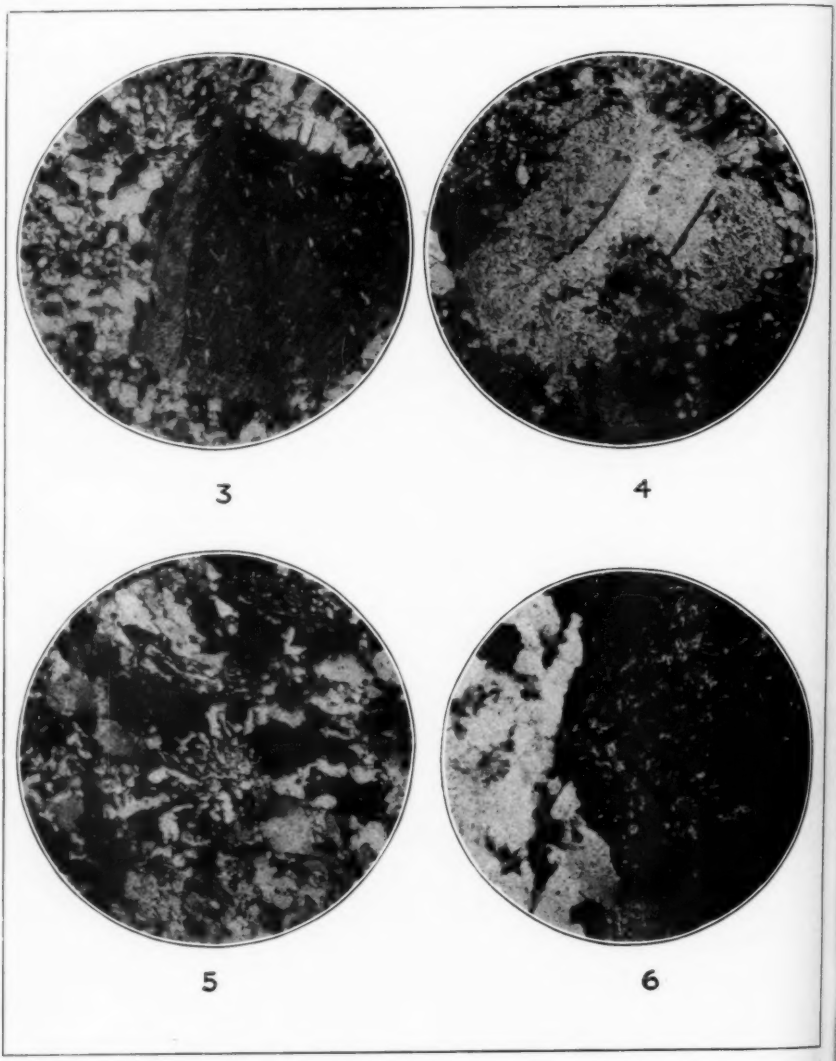


2

MICROGRAPHS OF LORRAIN QUARTZITE AND GNEISS



MICROGRAPHS OF KILLARNEY GNEISSES

PLATE 18.—*Micrographs of Killarney Gneisses*

SPECIMEN 3.—*Micrograph of Gneiss.* × 40

This specimen was collected a mile along the strike from specimen number 1, near the south point of George Island. It is clearly the geological continuation along the strike of specimen number 1 and it compares very closely with specimen number 2, just described, although collected half a mile away across the strike. The rock is a fine-grained quartzitic gneiss of dark red color, containing small flecks of pale mica and rather prominent unbroken crystals of orthoclase, some of which, under the microscope, show marked zones of growth and include fragments of quartz and microlites of amphibole. The plate shows a single individual crystal which is characteristic of a large group; it shows zonal growth and scattered inclusions. The inclusions are not represented in the surrounding matrix and appear to have grown either with or later than the feldspar host.[21]

SPECIMEN 4.—*Micrograph of Gneiss.* × 40

Pink gneiss collected at the northeast corner of George Island, within 200 feet of specimen number 1, on the east side. In the hand specimen and under the microscope the rock displays feldspar in irregular development within a fine-grained, quartzitic groundmass. Some of the feldspars include areas of clastic quartz within the feldspar crystal boundaries. This plate shows a nearly square-cornered feldspar with well developed twinning, having an irregular contact against the quartz grains along the crystal faces and an irregular area of included quartzite near the middle of the crystal.

SPECIMEN 5.—*Micrograph of Gneiss.* × 40

This specimen was collected 200 feet west of number 2. In the hand specimen the rock shows a much coarser texture than any of those preceding; furthermore, the texture is almost granitic. The rock is composed of great quantities of feldspar in a quartzitic matrix. This specimen seems to be mineralogically intermediate between a rock which is essentially quartzite but contains much feldspar, and a gneiss which is chiefly feldspathic but contains minor quantities of quartz. In this specimen quartz and feldspar seem to be in a balanced condition. The plate shows vermicular quartz in clublike masses invading and apparently replacing feldspar, a sort of micropegmatite. However, these features grade out into a region composed of discrete feldspars and individual quartz granules which show no intergrowth. The writer concludes that this represents syntetic rather than eutectic growth,[22] an indication of replacement.

SPECIMEN 6.—*Micrograph of Granite.* × 40

Collected 300 feet west of number 5. This may be considered a typical specimen of Killarney granite. It consists of coarse-grained feldspar and biotite with interstitial quartz. The feldspars are chiefly orthoclase with subordinate quantities of oligoclase-albite. The feldspars are singularly full of minute inclusions. The quartz in the rock is granular, of either clastic or cataclastic origin, apparently indistinguishable from the grains of quartz which inclose the feldspar 500 feet away (specimen 2) in the banded pink gneiss.

[21] Cf. W. H. Collins: Geol. Surv. Canada, Mem. 95, 1917, p. 60.

[22] J. J. Sederholm: Bulletin No. 48, Geological Commission of Finland, Helsingfors, 1916.

Cf. W. H. Collins: Idem, p. 62 and Pl. VIII B, 1917.

T. T. Quirke: Geol. Surv. of Canada, Mem. 102, 1917, pp. 51-55.

C. N. Fenner: Jour. Geol., vol. xxxiv, Supplement, 1926, pp. 750-754.

PLATE 19.—*Micrographs of Killarney Gneisses*

SPECIMEN 7*a*.—*Micrograph of Granite.* × 40

Locality is on the south side of Lamorandiere Bay. This rock contains inclusions of the Espanola formation, into which it is clearly intrusive. It appears to be a characteristic specimen of Killarney granite; the rock is undoubtedly intrusive in its relations to the Huronian series. In the field it displays what appear to be shearing planes, very similar in appearance to bedding planes. Under the microscope it shows large, irregularly shaped grains of feldspar full of inclusions, which are separated from one another by quartz grains, equidimensional in shape, very similar to those shown in the clastic rocks and supposed to be of the same origin. Another possibility is that this quartz may be cataclastic rather than clastic, and that it has been broken by shearing in the interstices of the feldspars after the feldspar and quartz had crystallized from a magma. It might be argued that the quartz is sufficiently brittle, so that it might have smashed into cataclastic zones without the tougher feldspars having broken appreciably. Under cross-nichols the individuality of the various minerals is plainly shown and certain cracks are seen to penetrate the feldspars. Any force which could have thus broken the feldspars would have broken also the quartz grains if they had been brittle enough to have broken previously into a cataclastic texture.

SPECIMEN 7*b*.—*Micrograph of Granite.* × 40

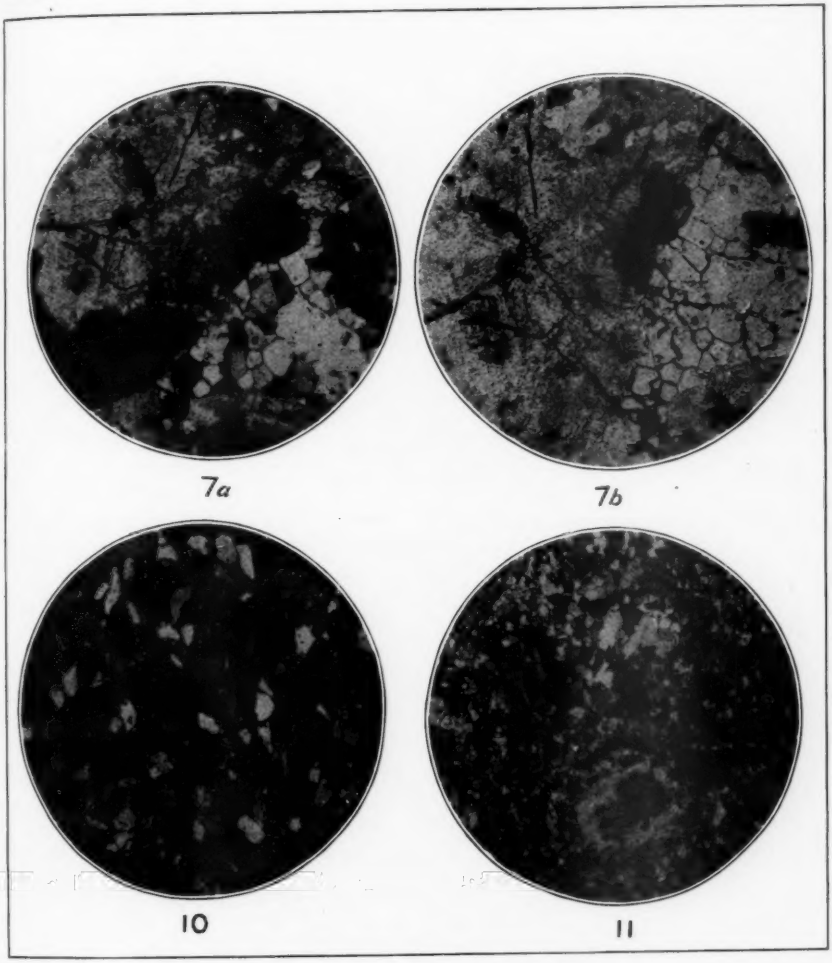
This photograph was taken with plain light for comparison with the preceding picture, which was taken with polarized light of the same specimen in order to show that the cracks which break the feldspars go around the quartz grains. Since the cracks were formed the spaces have been filled with ferrite, with the result that the cracks are easily followed in the grains under polarized light. Comparison of the two plates shows that the cracks run through the feldspar crystals, but they follow around most of the quartz grains. Evidently these quartz grains were individual, discrete particles previous to the development of the feldspars, and evidently they are not sheared pieces of crystalline quartz which filled the spaces between the feldspars after their formation from a granitic magma.

SPECIMEN 10.—*Micrograph of Quartzite.* × 40

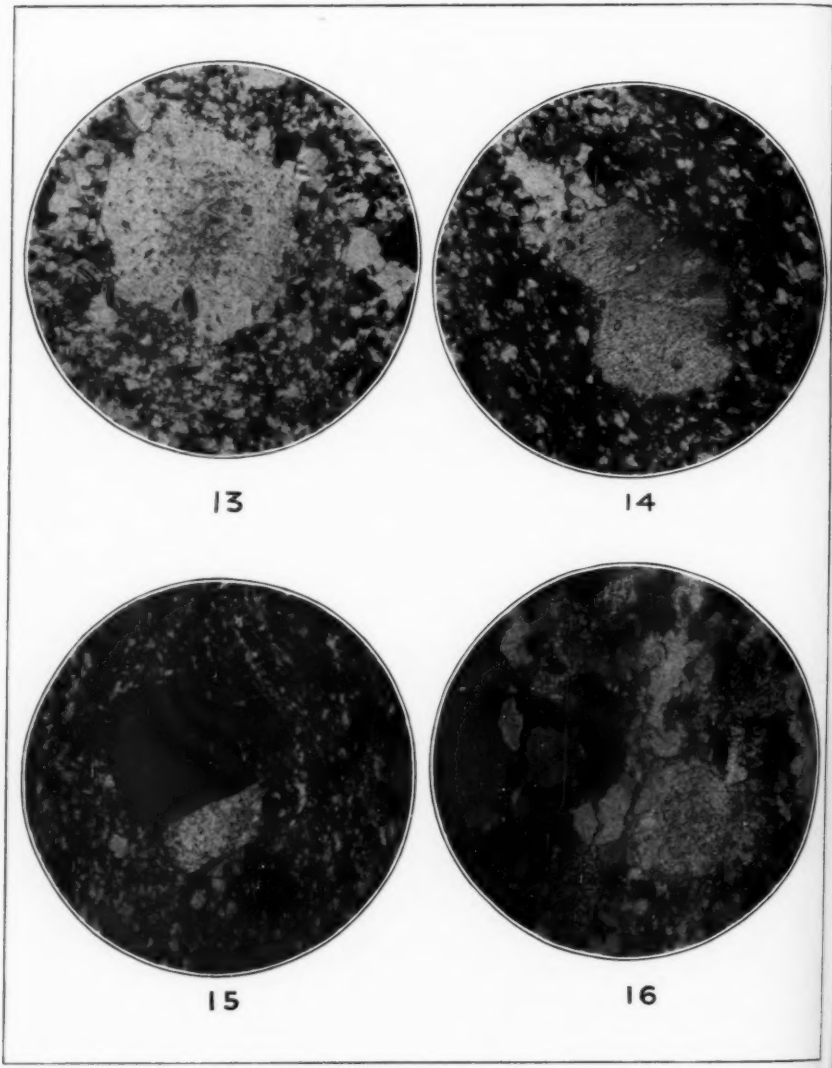
This represents the appearance of an impure quartzite which is part of the gradational graywacke between the top of the Gowganda and the lower part of the Lorrain formations. It was collected on the south side of Killarney Bay, near the Killarney granite. It brings another opportunity to study the appearance of the original quartz grains as displayed in the sediments.

SPECIMEN 11.—*Micrograph of Lorrain Quartzite.* × 40

This plate shows the first of a series of slides, including numbers 11 to 16, inclusive, collected across the transition from quartzite into granite, taken from a little island in Killarney Bay. This series has been collected within a space of less than thirty feet. Figure 11, plate 18, shows a single feldspar in matrix of fine-grained quartzite. The feldspar shows zonal growth and appears to have developed *in situ*.



MICROGRAPHS OF KILLARNEY GNEISSES



MICROGRAPHS OF KILLARNEY GNEISSES

PL. 20

PLATE 20.—*Micrographs of Killarney Gneisses*

SPECIMEN 13.—*Micrograph of Lorrain Quartzite.* × 40

This shows a feldspar crystal somewhat like that in specimen 11, plate 18, but shows more clearly a large feldspar unit which is isolated in quartzite. This feldspar crystal appears to have grown in place; it is made up definitely of an interior area, largely occupied by microlites, bordered by a zonal band, and in places extended beyond a fairly definite line of small inclusions. This crystal seems surely to have grown in place.

SPECIMEN 14.—*Micrograph of Lorrain Gneiss.* × 40

Irregular feldspars within a quartzite matrix show the inclusion of several quartz grains within the feldspar.

SPECIMEN 15.—*Micrograph of Lorrain Gneiss.* × 40

Shows a nearly square-cornered feldspar within a quartzite matrix which shows considerable shearing. The feldspar, however, shows only small displacements along twinning planes.

SPECIMEN 16.—*Micrograph of Granite Gneiss.* × 40

Appears to be characteristic of the intrusive granite. It consists largely of feldspars within a background of irregularly distributed quartz grains; much of the quartz is in stringy or plug-shaped masses within or between the main feldspar units, indicating replacement relationships. In the hand specimens number 16 is igneous in appearance, although closely related to those from 11 to 14 inclusive, all of which are definitely sedimentary.

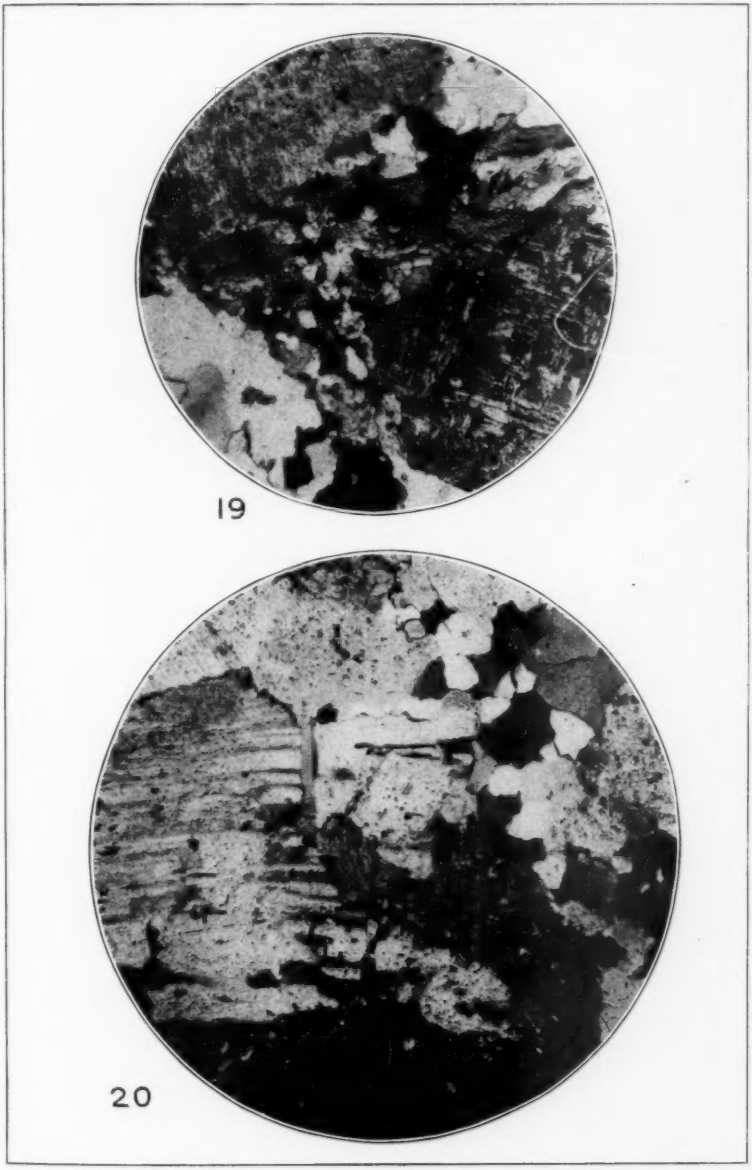
PLATE 21.—*Micrographs of Killarney Granite*

SPECIMEN 19.—*Micrograph of Granite.* × 40

This plate is designed to illustrate features which are typical of Killarney granite. The specimen was collected at the west entrance to Killarney Inlet. Under the microscope the rock may be seen to consist of large oligoclase-albite and orthoclase phenocrysts, about which there are areas of granular quartz of much smaller size. Many of the feldspar crystals are bordered with a line of mica and amphibole in very minute grains. Albite feldspars are partly replaced by orthoclase and microcline, and many of the orthoclase crystals are changed in part or entirely into microcline. In the plate the areas of granular quartz appear, and the alteration of orthoclase into microcline is well shown. One large crystal shows the alteration very plainly and the other only very vaguely.

SPECIMEN 20.—*Micrograph of Granite.* × 40

This again represents typical Killarney granite, collected within twenty feet of its intrusive contact against the Espanola formation, in Lamorandiere Bay. The feldspars are very large, generally spotted with inclusions, and consist of oligoclase and of orthoclase affording numerous examples of perthitic texture. In the plate a large crystal of oligoclase-albite is shown invaded by orthoclase. The orthoclase crystal in turn is cracked and invaded by the development of a later growing orthoclase feldspar. All these feldspars include certain quartz grains unaltered by the feldspar replacement. Figure 20, plate 21, may be compared with figure 7, plate 19. The specimens came from the same locality.



MICROGRAPHS OF KILLARNEY GRANITE

BULLETIN OF THE GEOLOGICAL SOCIETY OF AMERICA
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COUTCHICHING DELTA[1]

BY E. L. BRUCE

(Read before the Geological Society December 27, 1926)

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INTRODUCTION

For nearly forty years the so-called Coutchiching problem has been discussed by geologists working in the boundary area between the United States and Canada west of Lake Superior. The question has been the existence of any great mass of sedimentary material beneath the volcanics, to which Lawson gave the name of Keewatin in his report on the Lake of the Woods district. In most cases the arguments have dealt with accuracy or inaccuracy of field observations. In the heat of discussions it seems generally to have been forgotten that both the sediments, which all geologists agree are present, and the lavas of the generally accepted Keewatin series are formations individual members of which could not be expected to have a great lateral extent, since the sediments are terrestrial in character and since a single lava-flow can necessarily not extend to any great distance from the vent. If these facts are borne in mind, the diversity of field observations can be easily understood.

[1] Part of the symposium on Precambrian geology.

This paper is merely a summary of the present information concerning these old rocks and an elaboration of the hypothesis suggested in a previous paper,[2] as a possible solution of the Coutchiching problem.

The original Coutchiching

Rainy Lake District

In 1887 Lawson,[3] reporting on the geology of the Rainy Lake district, described two series of early Precambrian rocks—the Coutchiching, an ancient sedimentary formation, and the Keewatin, a volcanic series conformably above it. The chronological relation of the two groups has not been accepted by all geologists familiar with that region, and the International Committee to Standardize the Nomenclature of the Precambrian reported that the Coutchiching is actually above the Keewatin. Lawson restudied the section in 1911 and his final opinion is as follows:

"The oldest rocks of the Rainy Lake region are a thick series of sedimentary strata now chiefly metamorphosed to mica schist and paragneiss, to which, in the report of 1887, I gave the name Coutchiching series. This series is free from volcanic admixture. Resting on the Coutchiching series is the Keewatin, a series made up chiefly of volcanic rocks, but comprising also sedimentary strata intercalated with these."

Lawson's conclusions are, in the main, supported by Bruce,[2] who examined the area during 1924, incidental to a study of the gold deposits of Western Ontario. His rock descriptions and conclusions as to age relations are:

"Stratigraphically there is no evidence of any interval between the two rock series, and the contacts give no evidence of the order of superposition. Structurally, there seems no doubt that the Coutchiching sediments of this section lie beneath the Keewatin greenstones."

And again:

"In conclusion, therefore, it may be stated that the Coutchiching does form an important stratigraphic series in the Rainy Lake succession, and that it lies conformably below the Keewatin.[5]

"The common type is a grayish granular rock which weathers brown. The texture varies somewhat, but in most samples the chief minerals—quartz, feldspar, and biotite—are recognizable in the hand specimen. In some beds secondary porphyritic constituents, such as garnet and staurolite, are abun-

[2] E. L. Bruce: Journal of Geology, vol. 30, p. 470.
[3] A. C. Lawson: Memoir 40, Geological Survey of Canada, p. 5.
[4] E. L. Bruce: Ont. Dept. of Mines, vol. 34, pt. vi, p. 24.
[5] E. L. Bruce: Trans. Royal Soc. of Canada, vol. 19, p. 46.

dant. Stratification is clearly marked by color banding and by variation in grain or in kind of minerals." [6]

Grout,[7] working chiefly on the Minnesota side of Rainy Lake, has come to the conclusion that there the rocks of Coutchiching type are above the volcanics. He questions some of the structure as determined by Lawson, but admits that some of his (Grout's) findings, based on the size of grain in the sediments, may not be accepted by all, and, in fact, in his reply to Lawson's criticism, states:

"The mica schist, however, in that section (Bears Passage) is so far recrystallized that the top and bottom of the original beds can hardly be determined."

Grout concludes that the Coutchiching biotite schists occur only in small volume and do not deserve a separate formational name. His attitude is expressed in discussing the Rice Bay area:

"If we eliminate later intrusives, the formation is evidently small. If the thickness is reduced to allow for folding, intrusions, and errors in mapping, the Coutchiching becomes a series of thin beds, possibly 500 feet in the aggregate, such as might be interbedded in the Keewatin greenstone. At the top it grades by alternation into greenstone; greenstone occurs in the midst of it, and, since no conglomerate base is known, it seems likely that it originally had greenstone below as well as above, and deserves no formation name indicating a lower stratigraphic position."

The structure and thickness, as determined by Bruce in the Bear's Passage section, agrees approximately with the conclusion of Lawson. In other Canadian sections covered by Grout's work, other geologists have failed to agree with his geological succession. Tanton,[8] working in the Steep Rock Lake district, questions both Lawson's and Grout's classifications. He agrees with Grout that there is only one sedimentary series where Lawson and McInnes had mapped two, but he considers that it lies beneath the Keewatin.

"The examination of the rocks from Long Lake to the north end of Lerome Lake, therefore, indicates that there is but one regionally metamorphosed sedimentary series present.

"Without exception, it was found that the tops of the beds near contact are toward the north, so that the greenstones, classified as Keewatin, must overlie the sediments rather than underlie them."

[6] Ont. Dept. of Mines, vol. 34, pt. vi, p. 23.
[7] F. Grout: Bull. Geo. Soc. Am., vol. 36, pp. 363.
[8] T. L. Tanton: Trans. Royal Soc. of Canada, Sec. IV, 3d series, vol. 22, pp. 45-46.

THE COUTCHICHING PROBLEM

Grout's statement of thickness of actual sediments may be correct, but it hardly justifies the corollary which he subjoins. What the beds below the exposed sediments may be, no one knows. The desirability of

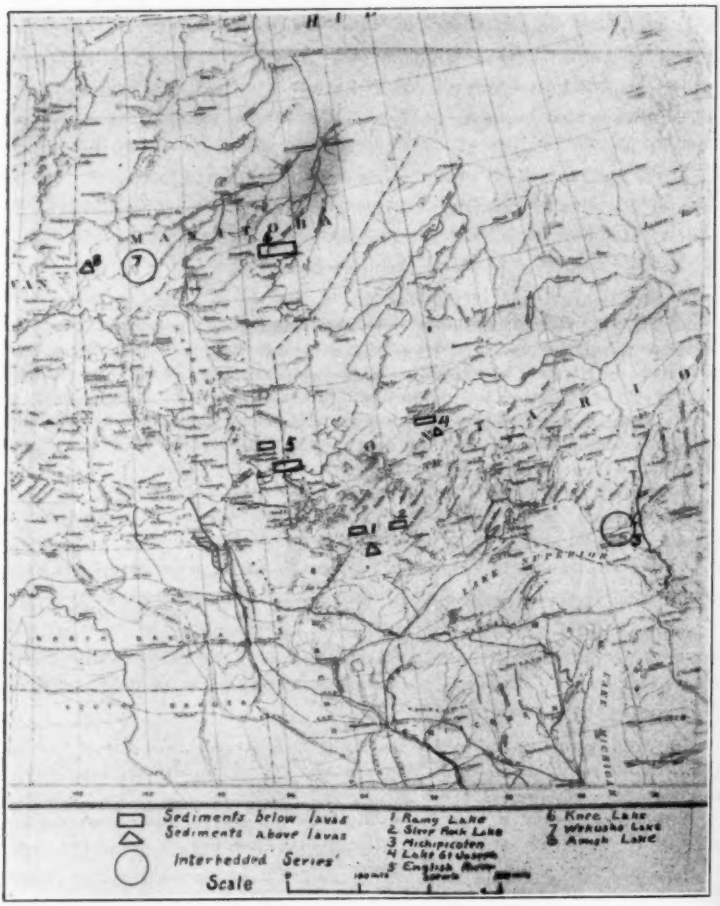

FIGURE 1.—*Map showing Distribution of early Precambrian Sediments*

a formational name depends on other things than the thickness of the beds at this one place. When Lawson made his original study of the area, but isolated sections of Precambrian rocks had been examined

at all, and few of these, on the Canadian side of the line, in any detail. Even at the time of his second examination, merely a narrow fringe along the southern edge of the shield had been mapped in more than preliminary fashion. Now, however, with the extension of prospecting into the hinterland, many widely scattered sections have been fairly thoroughly studied, and a review of the data collected may show in broader perspective the relations of the earlier Precambrian rocks. So far as reported in the literature, no sediments exactly similar to the Coutchiching biotite, staurolite, and garnet schists and gneisses occur with lavas in northeastern Ontario—that is, in the Temiskaming subprovince. Districts where such sediments are described are:

Region north of Sault Sainte Marie, including Michipicoten.
Region northwest of Lake Nipigon.
Rice Lake area of eastern Manitoba.
Oxford and Knee Lake area, northeastern Manitoba.
Wekusko Lake and Athapapaskow Lake areas, extending westward to the Saskatchewan-Manitoba boundary.

Other Areas of Rocks of the Coutchiching Type

Michipicoten district

In the Michipicoten district a band of sediments known as the Dore series lies between volcanic formations. Conglomerate and graywacke form the greater part of the total thickness, but some slate also occurs. The thickness of the sediments and some interbedded volcanics is given as about 9,000 feet in some places.

The true sediments grade downward into volcanic fragmental rocks. Above, the Dore sediments are much more sharply divided from overlying dark-colored volcanics, but even that contact is apparently gradational.

The rocks of the Dore series are believed to have been deposited as terrestrial sediments.

"The Dore series has the aspect of a land formation rather than one formed in the sea or in a lake. It has no sharply defined erosional base. It varies enormously in thickness, and within short distances. . . . The series contains volcanic rocks apparently interstratified with the sediments. There is little assortment of materials, with a dearth of clayey and other fine-grained materials and no known chemical sediments."[9]

In an area 20 miles north of Sault Sainte Marie, Ontario, Sir Stop-

[9] W. H. Collins, T. T. Quirke, and Ellis Thompson: Geological Survey of Canada, Memoir 147, p. 22.

ford Brunton [10] found a series of ancient schists which consists of volcanic flows and tuffs and some interbedded conglomerates. The sedimentary beds are discontinuous and are believed not to be basal conglomerates.

REGION NORTHWEST OF LAKE NIPIGON

Northwest of Lake Nipigon, which lies directly north of Lake Superior, two areas have been mapped in some detail. The area around Lake Savant was mapped by Moore in 1910, that at Lake Saint Joseph by Bruce in 1921. The latter area lies 200 miles northwest of Lake Nipigon; the former between Lake Nipigon and Lake Saint Joseph.

At Lake Saint Joseph the early geological history is described thus:

"The geological history indicated by the formations just described begins with an early period of ordinary sedimentation in a country of comparatively low relief, so that the sediments consisted chiefly of sandy material with practically no coarse fragments. At various times conditions in restricted basins were favorable for the accumulation of iron-bearing beds. The area affected by those conditions was small and the time during which they existed was short, during the early part of the sedimentary epoch, but towards its close large areas of this kind existed for periods sufficiently long to form beds of iron minerals some hundreds of feet in thickness."

After the deposition of the main iron-bearing beds came the beginning of volcanic activity. Along with the volcanic effusions, there were formed some ordinary clastic sediments, probably in local basins.[11]

Toward the eastern end of Lake Saint Joseph some conglomerates occur in the sedimentary group.

At Lake Savant the sedimentary rocks are apparently exactly similar to those at Lake Saint Joseph, but Moore placed them above the basic lavas and classed all of them as Keewatin in age. The following are excerpts from his report:

"When the rocks (of Lake Savant area) are compared with those of other Keewatin areas, there are striking differences. The most noticeable are the great amount of graywacke occurring in the Keewatin, and the presence of considerable amounts of a fine-grained, gray biotite gneiss which appears to correspond closely with the gneisses described as Coutchiching by Lawson." [12]

Concerning the age relationship of this rock and the volcanic rocks, the following statement is made:

"The graywackes have a composition such as to suggest that their origin was from rather basic rocks, and it seems probable that these gneisses may

[10] Sir Stopford Brunton: Geological Survey of Canada, Summary Report, pt. D, 1921, p. 28.

[11] E. L. Bruce: Ont. Dept. of Mines, Ann. Rept., vol. 31, pt. viii, p. 22.

[12] E. S. Moore: Ont. Bureau of Mines, Ann. Rept., vol 19, pt. i, p. 178.

have been developed by the disintegration and partial decomposition of the more acid rocks, which form a considerable portion of the complex Keewatin series."

Moore states that there is an apparent gradation of fine-grained, light gray biotite gneiss into acid eruptives, from which he believes the gneiss to have been derived.

EASTERN MANITOBA AND NORTHWESTERN ONTARIO

In that part of the Province of Manitoba lying east of the south end of Lake Winnipeg, J. F. Wright [13] has described at Beresford Lake a succession of which the oldest rocks are sediments consisting of quartzite, graywacke, and arkose with conglomerate bands, argillite, slate, garnet-gneiss, and biotite schist. The base is not exposed. Apparently conformably above these are interbedded sediments and volcanic rocks, consisting of acid and basic flows and volcanic fragmentals. Still higher are andesites, basalts, rhyolite, trachyte, and dacite flows with no sediments. Concerning the origin of the sediments he writes:

"It is very probable that the materials forming those rocks were deposited in shallow water, under near-shore or possibly continental conditions."

The thickness of this conformable series of lavas and sediments is stated to be very great; quartzose sediments alone are about 10,000 feet in thickness.

Wright,[14] in 1924, working in an area farther south than his area of 1923, found similar conditions to those in the Beresford Lake district and summarizes the succession from the bottom up as mica schists with local beds of conglomerate and sediments of some variety interbedded with tuffs and flows.

During the field season of 1926 Dr. Wright continued the investigation of these rocks eastward toward the Ontario boundary, and is of the opinion, as a result of an exploration trip eastward into Ontario, that the sedimentary series of Manitoba may be continuous with the sedimentary series along the English River.

The geology of that area was described as early as 1893 by the late Dr. D. B. Dowling, and in 1922, in somewhat more detail, by E. L. Bruce. The character of the sediments is described as follows in a private communication:

"Gneisses of sedimentary origin underlie a large part of the upper English

[13] J. F. Wright: Summary Report, Geological Survey of Canada, 1923, pt. B, pp. 95 to 97.

[14] J. F. Wright: Geological Survey of Canada, Summary Report, 1924, pt. B, p. 58.

River basin. Various types of gneisses could be designated, depending on the mineral composition, but all are, without doubt, of sedimentary origin.

"At station 304, on the mainland, west of Island 14, Shallow (Pakwash) Lake, a zone of conglomerate is interbedded with gneiss. The matrix of the conglomerate is biotite gneiss, similar to that in which no pebbles occur, and, aside from the pebbles, the rock would be classified as a very thoroughly recrystallized micaceous quartzite. All the pebbles are either quartz or granite."[15]

Iron formation also occurs in some volume in this series and the whole is believed to be of sedimentary origin. As to the origin of the early Precambrian rocks the following statements are made:

"The earliest period in the geological sequence may have been either one of deposition of sediments or one of igneous activity. It is plain, however, that in very early geological times thick deposits of sediments were laid down. . . . On the whole, the conditions that seem most likely were those of deposition on broad floodplains of the sand derived by the erosion of areas of siliceous rocks."[16]

NORTHERN MANITOBA

During recent years several adjacent areas, forming an almost complete section across northern Manitoba, have been geologically mapped. The character of the early formations of that region were summarized in a paper before this Society in 1920.

"In some districts the volcanic periods were preceded by periods of terrestrial sedimentation; in other areas these early periods of sedimentation continued long after the extrusion of lavas had ceased."[17]

Areally the distribution and succession shows that in western Manitoba and eastern Saskatchewan the dominantly sedimentary series lies above the volcanic rocks. Farther east the two are interbedded. In the northeastern part of the province the sediments lie below the lavas.[18]

The Coutchiching Delta

From the foregoing it is clear that sediments were abundant in the earliest Precambrian rocks in an area extending northward from Rainy Lake for a distance of at least 450 miles, northwestward nearly to the western boundary of Manitoba, a distance of 500 miles, and northeast-

[15] Ont. Dept. of Mines, Ann. Rept., vol. 33, pt. iv, pp. 5-6.
[16] Op. cit., p. 10.
[17] F. J. Alcock and E. L. Bruce: Bull. Geol. Soc. Am., vol. 32, p. 291.
[18] Op. cit., table facing page 270.
E. L. Bruce: Also, Memoir 105, Geological Survey of Canada.
F. J. Alcock: Also, Memoir 109, Geological Survey of Canada.
E. L. Bruce: Summary Report, 1919, Geological Survey of Canada.

ward at least to the Albany River, a distance of 300 miles. Many of these sediments are similar lithologically. They are commonly biotite schists or gneisses and garnet or staurolite schists. In some localities they lie conformably beneath lava-flows, similar lithologically to the Keewatin rocks of the Lake of the Woods and Rainy Lake. In others the two types are interbedded. In still others the sediments are the younger. It seems unlikely that errors in observation explain the difference in conclusions reached by various observers, especially in view of the accurate and detailed work carried on for so many years on the United States side of the line. The difference must, therefore, be explained by the nature of the formations.

A study of the published descriptions shows some noteworthy similarities. There are no limestones; all sediments are clastics, excepting possibly some beds of iron formation, and all observers agree in assuming dominantly terrestrial conditions of deposition.

Sections across the area outlined just above bring out significant relationships. A section westerly from the Knee and Oxford Lake area to the Athapapaskow-Amisk Lake area of western Manitoba has at the eastern end a thick series of mica gneisses or schists, quartzites, slates, and rather abundant conglomerate. Conglomerates are present in some volume at Oxford Lake. At Wekusko Lake, 200 miles farther west, the rocks are gneisses, staurolitic, garnetiferous, and biotitic schists, with some conglomerate.[19]

The order of the rocks is as follows: At Knee and Oxford lakes the sediments lie below the volcanics; at Wekusko Lake the two formations are interbedded; at Amisk Lake the schists are thought to lie above, but the relationship is not proved. Southward from Knee Lake there lies a great area not yet examined in detail, and it is nearly 300 miles to the Rice Lake and English River district. There the rocks are sedimentary gneisses, chiefly a micaceous variety, with garnet and some staurolite. Conglomerate lenses have been observed, but are not common. Southeast another hundred miles lies the Rainy Lake district, with its Coutchiching sediments practically lacking in conglomerates, lying below volcanics on the north shore, possibly interbedded or above the volcanics farther south. At Lake Saint Joseph, 300 miles southeastward from Knee Lake, the gneisses and iron formation lie below lava-flows.

In character all of these sediments are those of floodplain and delta deposits. Whether or not they belong to one great outwash plain, the

[19] E. L. Bruce: Summary Rept., Geological Survey of Canada, 1919.
F. J. Alcock: Memoir 119, Geological Survey of Canada, 1919.
E. L. Bruce: Memoir 105, Geological Survey of Canada, 1919.

record is too fragmentary to determine, though further study may fill in some of the gaps. However, erosion in many places has exposed the underlying granite intrusives and has destroyed the fragmental rocks if they ever existed. Perhaps the area north of Sault Sainte Marie, at least, was a separate fan. So far, however, as the western area is concerned, it seems possible to picture it as a great floodplain and delta deposit grading from coarse conglomeratic river deposits at Knee Lake to the fine-grained sandy to clayey beds of the delta at Rainy Lake, 400 miles to the south, and of Wekusko and Amisk lakes, 250 miles to the west.

The characteristics of the rocks of this Coutchiching type are those typical of floodplain and delta deposits, if one imagines the sediments severely metamorphosed, so that the sands become gneisses and the muds, staurolite, garnet, and mica schists. The variable thickness in short distances, the variable character of the beds, the cross-bedding, are exactly reproduced in sections of those old beds.

If it be granted that the early Precambrian sediments may have had such an origin, the harmonizing of the diverse field relations observed becomes less difficult. In Barrell's discussion of delta deposits and delta conditions [20] he shows how elevation of the land or depression of the sea bottom affects the strandline and the relation of floodplain to true delta deposits. In general, the normal development will lead to the building forward of the delta and floodplain out to the limit of the shallow water. where the forward growth is checked by the transporting action of ocean currents. How far from the original river mouth this may be and how long it may take depend on conditions. Suppose that a great river or several rivers in early geological times flowed downward from a great Hudsons Bay landmass, such as has been suggested by Cooke [21] in his discussion of the relation of the Precambrian of northern Quebec to the Grenville series.

Deposition, which may have started far to the north of Rainy Lake, may have advanced southward and westward at various rates and with many halts and possible regressions, as the strandline moved northward by elevation of the sea bottom or southward before the deposition of the debris carried down by the river or rivers. This also might be complicated by possible elevation of headwater areas. In general, however, there would be progressive overlap of the sediments outward from the central part of the area. It is clear that, if such were the case, and if volcanic rocks were extruded at any period during the existence of the

[20] Bull. Geol. Soc. Am., vol. 23.
[21] H. C. Cooke: Journal of Geology, vol. 27, p. 370 et seq.

delta, there would necessarily be different relations of sediments to lavas in various parts of the floodplain and delta—that is, lavas flowing out beyond the margin of the delta would lie on beds older than the sediments, and might later be covered by the overlapping delta deposits. In the floodplain or delta area the lavas would lie on the sediments. Along the delta margin, if the period of igneous activity were of some duration, the two rocks would be interbanded.

Chronologically the ancient sediments and the lava-flows are in part contemporaneous, but the lower sediments of the northern areas probably are much earlier than the period of volcanic activity. Detailed information may prove that there are important unconformities even within the series. For the present, however, the logical course would seem to be the retention of the term Coutchiching for this series of sediments, beginning in the earliest known times, antedating the period of Keewatin volcano activity, and possibly continuing after its close. It may be permissible even to suggest that it is in part contemporaneous with the Grenville period of limestone deposition.

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GEOLOGY OF THE CUYUNA RANGE[1]

BY GEORGE A. THIEL

(Read before the Society December 27, 1926)

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INTRODUCTION

Since the discovery of the Cuyuna district in central Minnesota one of the most perplexing problems has been the geological succession of the strata and their correlation with the known formations of the Lake Superior district. Undoubtedly the chief reason for the divergent opinions with respect to correlation lies in the fact that there are but a limited number of surface exposures in the entire region of the Cuyuna Range, and those present are at a considerable distance from the productive portion of the range. In fact, the Cuyuna region has very few of the surface features that are frequently associated with a Lake Superior iron range, such as conspicuous topographic ranges with characteristic trends and numerous rock exposures. The country is flat, with a maximum relief scarcely over 150 feet. It is covered with a heavy mantle of glacial drift, with numerous morainic hills, lakes, and swamps.

The writer wishes to gratefully acknowledge the assistance offered by various commercial firms through access to private reports and maps. Especially the E. J. Longyear Company for magnetic surveys of the region northeast of Aitkin; to Mr. M. C. Lake, of the M. A. Hanna Company, for maps and surveys of the region east and south of Emily; to Dr. C. K. Leith for access to reports and drill cores of the Cuyuna area,

[1] Part of the symposium on Precambrian geology.
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and to many well-drillers for logs of the surface formations and the character of bedrock.

The work in the field has been in charge of Dr. W. H. Emmons, Director of the Minnesota Geological Survey, and Dr. F. F. Grout, of the University of Minnesota. Their assistance and criticisms are gratefully acknowledged.

Résumé of Correlation

Geological investigations dealing with the relation of the rocks in east-central Minnesota date from the early works of Irving and Sweet on the geology of northern Wisconsin.[2] This work was followed by the investigations of the United States Geological Survey under the direction of Irving, assisted by Van Hise and Merriam.[3] At this time the slates and schists occurring along the Saint Louis and Kettle rivers were connected directly with the Animikian rocks in the Mesabi, and all Animikian formations were considered as a slightly metamorphosed phase of Huronian rocks, without recognition of difference in age.

Later Van Hise [4] mapped the Saint Louis slate, extending across central Minnesota, including the present Cuyuna district and Little Falls regions. It was bounded on the west and south by granite classified as Archean. At approximately the same time N. H. Winchell, Upham, and others of the Minnesota Geological Survey mapped the Animikian to include the original formations by that name north of Lake Superior, the iron-bearing series of the Mesabi, and the slates occurring along the Saint Louis River, but they did not include the slates and schists of the Kettle River region. These were classified as Keewatin.

Spurr classified the slates and schists of the Kettle River and Little Falls regions as Lower Huronian [5] and considered them directly continuous with the Saint Louis slate. Leith [6] in 1903 followed Spurr's classification and placed the slate outcrops at Carlton, Cloquet, and Little Falls, in the Lower Huronian. He suggested that they were southwest of an iron-bearing belt that extended southwestward from the western end of the Mesabi district and then turned eastward through the present Cuyuna region toward Duluth. The southern boundary of this hypothetical belt was determined by several quartzite exposures in the Dam

[2] R. D. Irving: Geol. of Wis., vol. iii, 1880, p. 18.
E. T. Sweet: Geol. of Wis., vol. iii, 1880, p. 334.
[3] R. D. Irving: U. S. Geol. Survey, Third Ann. Rept., 1883.
[4] C. R. Van Hise: U. S. Geol. Survey Bull. 86, 1892.
[5] J. E. Spurr: Am. Jour. Sci., 3d ser., vol. 148,1894.
[6] C. K. Leith: U. S. Geol. Survey Mon. 43, 1903.

Lake region which were considered the equivalent of the Pokegama quartzite.

Since the discovery of the ore-bearing formations on the Cuyuna Range a number of reports have appeared, and in each the slates and schists of central Minnesota are classified as Upper Huronian and are correlated with the Virginia slate of the Mesabi district. The iron-bearing formation of the Cuyuna, called the Deerwood member, is described as "beds and lenses in the Virginia slate."[7]

During the early period of development of the Cuyuna Range Mr. Carl Zapffe, who was closely identified with exploratory work then in progress, published a series of articles in which it was clearly indicated that the tendency of the time was to correlate the Deerwood formation with the Biwabik formation of the Mesabi Range. However, it was pointed out that the base of the Cuyuna series had not been established; that lenses of quartzite such as those found at the Moroco pit were frequently encountered in drilling and were completely surrounded by green slates and schists. Zapffe[8] presented a basal quartzite member as only "an assumption, and a possibility if the Cuyuna and the Mesabi series actually were one and the same."

Diverse Opinions on Correlation

1. The Cuyuna ore-bearing member, the Deerwood formation, may be equivalent and coextensive with the Biwabik formation.

2. The Cuyuna ore-bearing formations may be lenses and beds encased in a thick green schist series composed largely of volcanic materials and clastic sediments now more or less schistose. This group may be a part of the Virginia slate series.

3. The ore-bearing member of the North Range of the Cuyuna may be much older than that of the South Range, with a structural unconformity separating the two.

4. The Cuyuna series may be younger than Upper Huronian, as represented by the Animikian group, and overlap it in the region to the southwest of the west end of the Mesabi Range. It may be correlated with the Copps formation of the Gogebic or the iron-bearing members of the Crystal Falls, Iron River, and Florence districts.

5. A great unconformity may separate the Carlton or Virginia series from the Cuyuna series.

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[7] E. C. Harder and A. W. Johnston: Minn. Geol. Survey Bull. 15, 1918.
[8] Carl Zapffe: Lake Superior Mining Institute Proc., vol. xxiv, p. 89, 1925.

Discussion

It is evident from the list of opinions given above that the stratigraphic position of the Cuyuna iron-bearing series is still an open question. It is equally evident from the lack of outcrops that the relations of these rocks are not likely to be completely demonstrated. However, as exploratory work progresses, new data may be weighed in the light of present day interpretations and applied where the evidence is most convincing.

The interpretation that considers the Deerwood formation equivalent to and co-extensive with the Biwabik formation has for its basis a number of factors. The general structure of the Cuyuna formations, with

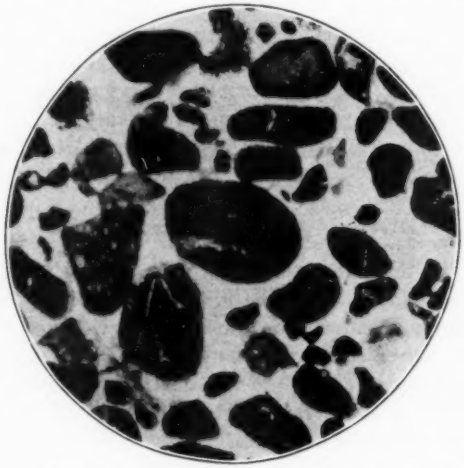

Figure 1.—*Greenalite Structures in granular Chert.* × 60
From North Cuyuna Range.

a northeast-southwest trend and a dip toward the southeast similar to the Biwabik formation, led the early workers to consider the two formations closely related. This structural similarity is supported by stratigraphic similarities, both above and below the iron-bearing series and within the ore horizon itself. In the Deerwood series of the North Cuyuna are slaty and cherty beds somewhat similar to the alternating cherty and slaty horizons of the Biwabik formation. Furthermore, the quartzites to the southeast of the Cuyuna were considered basal and equivalent to the Pokegama quartzite of the Mesabi Range. It should be noted, however, that the extent and thickness of these quartzite beds

and those to the northwest of the productive area of the Cuyuna have never been determined and their distribution as small lenses in various parts of the range renders them unsafe as a horizon-marker for correlation.

Petrographic studies by the writer have revealed the presence of greenalite structures and granular-textured chert in the cherty phases of the North Cuyuna series (figures 1 and 2). This type of chert has been considered characteristic of but one period of Huronian sedimentation in the Lake Superior region and should therefore be of stratigraphic value. However, Dr. F. F. Grout and Dr. G. M. Schwartz have recently discovered somewhat similar structures in the Rove slate at a considerable

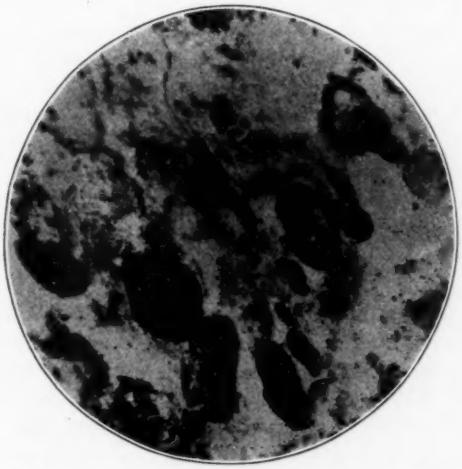

FIGURE 2.—*Altered greenalite Grains partially replaced by finely granular Magnetite* (black). × 60

From cherty phase of Deerwood iron formation.

distance above the Gunflunt formation.[9] This formation is generally considered the equivalent of the Biwabik formation of the Mesabi Range. Since the granules in the Rove slate are younger than Biwabik in age, those of the Deerwood may also be younger than the Biwabik formation. One must conclude, therefore, that the presence of greenalite structures is no longer a safe criterion of correlation in the Lake Superior region.

That the Cuyuna series may be younger than the Upper Huronian and overlap the Animikian sediments to the southwest of the west end of the

[9] Personal communication.

Mesabi Range is the most recent interpretation of Cuyuna Range structure. From a study of drill cores and field relations, Zapffe concludes that typical Cuyuna green schists overlie slates similar to the Virginia slates, and that a structural break separates the two series. This conclusion is supported by the fact that several hundred feet of soft, light-colored, flaky and unconsolidated material that is not glacial drift was penetrated by drills in the region north of the Cuyuna Range before the Virginia slates were encountered. This material is considered as unconsolidated Cuyuna green shist, as it is in a region in which deformation is of a minor order, and therefore "the Cuyuna rocks would not be likely to be consolidated."

From observations and consultations with well-drillers in different parts of the State far removed from the Cuyuna district, and from conferences with Dr. Ira Allison, who has also examined drillings and interviewed a great number of drillers in the northwestern part of the State, in collecting data on water supply, the writer is of the opinion that the presence of the unconsolidated material is a very unreliable criterion of correlation. Such soft, flaky, sericitic material is very characteristic as residual material in both granitic and slate areas of the State. This is especially the case where Cretaceous clays have not been removed or where they have been worked over and form an essential part of the drift. The material is undoubtedly residual, as it contains fresh mineral fragments, including feldspars. It lies below the Cretaceous and grades into fresh rock with depth. All gradations have been collected and examined. This material is not found in place in eastern Minnesota, where the glacier scoured to fresh rock and where the glacial till and bedrock now present a sharp contact. The Virginia slate or any similar slate, when weathered, will form a product similar to the residue described.

Another difficulty in the minds of those who have read the most recent discussions on Cuyuna correlation is the presentation of a sequence of strata in which "slaty material with steeply inclined schistosity" overlies flat-lying banded slates. Such a structure is difficult to visualize and more difficult to explain if the upper bed is considered the younger. An unconformity may separate the Virginia or Carlton series from the Cuyuna series, but the evidence to date is still very inconclusive.

Mr. Roberts is of the opinion that a batholithic granite mass intrudes the Huronian sediments, but does not cut the Cuyune series, and that the "erosion of an intruded formation on a scale sufficient to expose the core of a granite batholith before a later formation is laid down is evi-

dence of a great unconformity." Structurally, such a statement is correct. However, we can not ignore the fact that many granite stringers

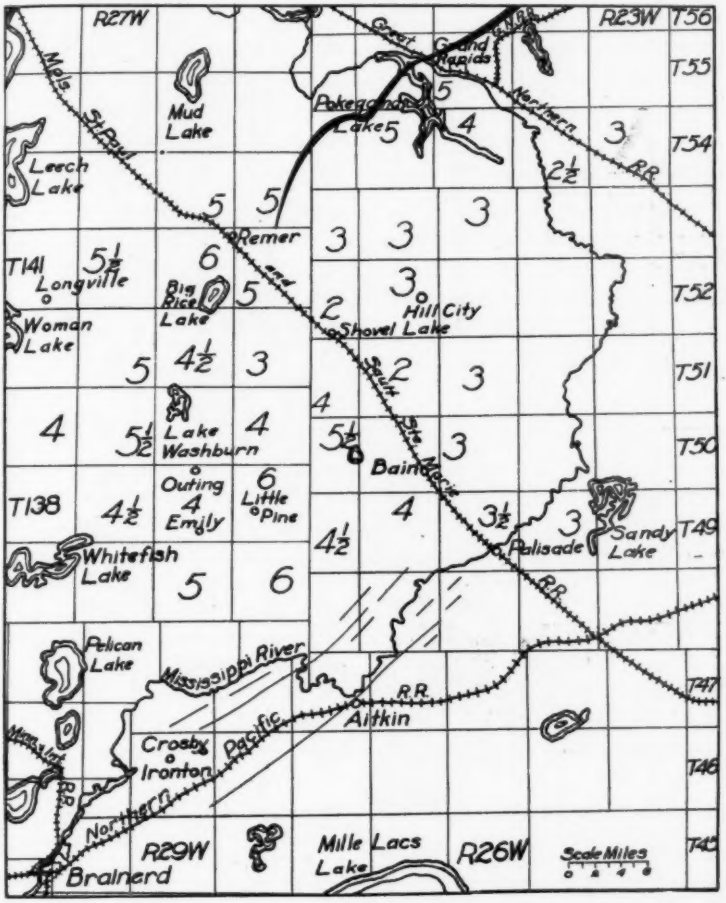

FIGURE 3.—*Region between the west end of the Mesabi Range and the east end of the Cuyuna Range*

A generalized representation of the results of magnetic surveys is presented. The numbers are merely an indication of the relative attraction of different regions. The townships with the low numbers are uniformly low, whereas those with the higher numbers may show local areas with attractions much higher or lower than those indicated.

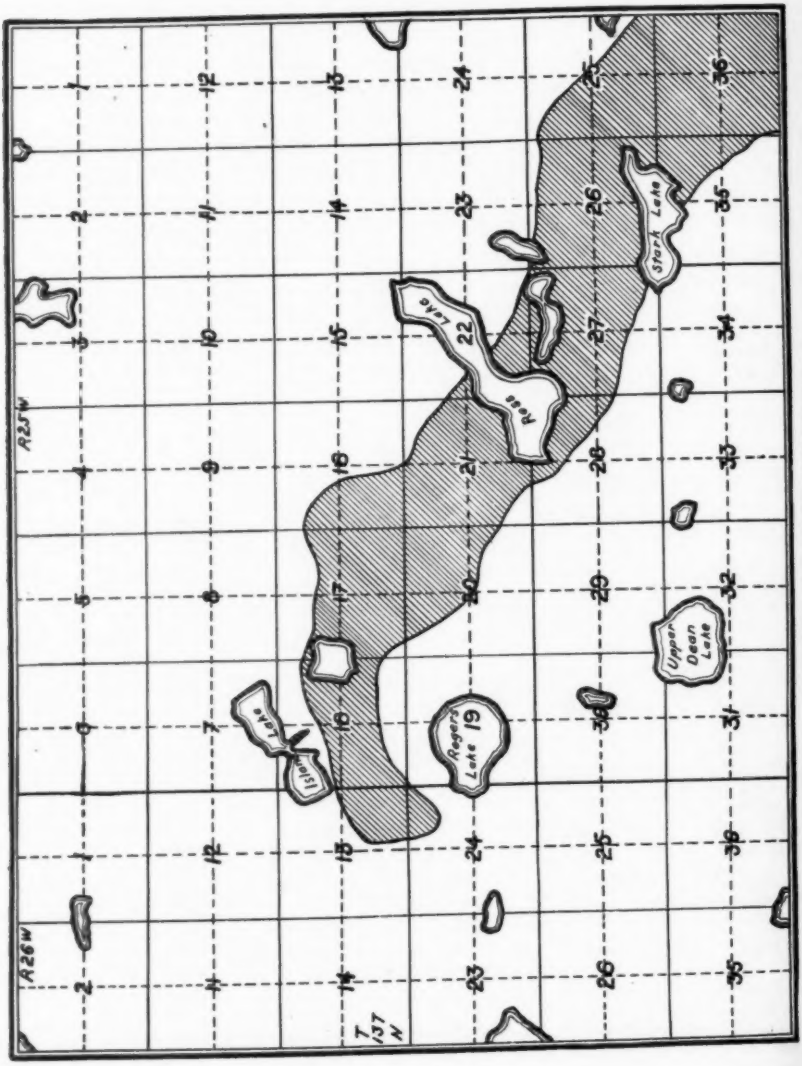

FIGURE 4.—*Map of Ross Lake Region*

Showing a zone of magnetic attraction extending in a northwest-southeast direction. Modified from a survey by M. C.

and pegmatite veins cut the Deerwood member of the Cuyuna series,[10] and field relations suggest that they owe their origin to the larger granite masses to the southeast of the range. These are the granite areas referred to as being older than the Cuyuna series. Harder and Johnston classified the granites of this region as Keweenawan. Whatever the field relations of the slates may be, granites younger than the Cuyuna series intrude both.

Magnetic Survey Data

Magnetic surveys in the region north of the Cuyuna and southwest of the Mesabi ranges were conducted by the writer during the past two field seasons. The results are not convincing, but they may be suggestive from the standpoint of correlation, for they reveal the presence of a number of areas with appreciable magnetic variations. Some of the areas have already been drilled and iron-bearing formations and ore have been encountered; others, where drilling has revealed the presence of ore, show no departure from the regional attraction. This is especially true in the region southwest of Emily, where an ore body is located under approximately 400 feet of overburden. Perhaps the point of greatest importance brought out by the survey is the uniformly low attraction over the so-called Virginia slate area south of the western portion of the Mesabi Range. After a number of areas had been mapped in detail, it was decided to attempt long-distance traverses across the whole territory between the two ranges. The traversing was done by car and two dip needles were used, one serving as a check for the other. Readings were taken every mile or every half, quarter, or tenth of a mile, as the region might warrant. Traverses south of Nashwauk, Bovey, Marble, Coleraine, and Grand Rapids showed a decrease of from one to three degrees in the regional attraction several miles south of the north margin of the Virginia slate. The normal attraction of the slate area from Pokegama Lake toward Hill City and Shovel Lake is several degrees less than that of the region toward Remer and Big Rice Lake. On the basis of such work a boundary zone may be established that roughly separates the two areas (figure 3).

When the results of this magnetic work are compared with those of commercial firms in adjoining regions, it is found that in the region northeast at Aitkin, Leith's line of maximum magnetic attraction dwindles and frays in a number of very light lines and then disappears. In the region of Lake Esquagama a northwest-southeast line frays in

FIGURE 4.—*Map of Ross Lake Region*
Showing a zone of magnetic attraction extending in a northwest-southeast direction. Modified from a survey by M. C. Lamb.

[10] George A. Thiel: Econ. Geol., vol. 19, 1924. Eng. and Min. Jour.-Press, vol. 121, 1926, pp. 687.

the general direction of Bain, and in the region southwest of Remer the general regional attraction decreases in the direction to the south of Longville.

Perhaps the most significant point is the fact that all of the iron formations revealed by drilling between the two ranges have been found

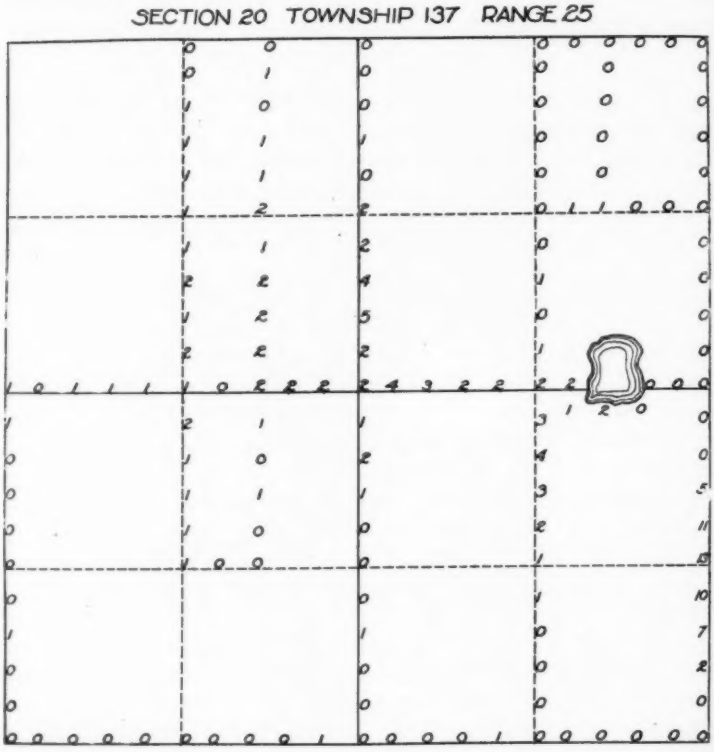

FIGURE 5.—*Map of Section 20, Township 137 North, Range 25 West, of Ross Lake Region*

Showing the results of a magnetic survey. See figure 4 for the extension of the magnetic area.

to the west of the area of uniformly low attraction. An ore body in Ross Lake township, township 137 north, range 25 west, contains ore very similar to the manganiferous ore of the North Cuyuna and it is located in a zone of magnetic attraction that has a definite northwest-southeast trend (figures 4 and 5). It is not safe to overemphasize the

importance of a northwest-southeast trending magnetic zone to the north of the Cuyuna Range, for in some regions neighboring the Cuyuna magnetic areas have been found over intrusive gabbros that cut the slates.[11] However, in most cases such intrusives follow the structure of the slate or iron formation they intrude. No gabbro has been encountered in the Ross Lake region, and the northwest trend of a manganiferous ore zone suggests a continuation of the Cuyuna formations in that direction. Other ore bodies have been located farther toward the north and west, but in each case they are within the limits of the area with a regional magnetic attraction slightly above that of the slates farther toward the east.

It is thus evident that the gap between the two ranges is becoming smaller and smaller; but, in spite of the narrowing of the zone that separates them, their ores are so unlike that the age relations of the two series can not be definitely established until more structural and petrographic data become available.

[11] G. A. Thiel, Iron sulphides in magnetic belts near the Cuyuna Range: Econ Geol., vol. 19, pp. 466, 1924.

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VOL. 38, PP. 795-804 DECEMBER 30, 1927

STRATIGRAPHY OF THE GRENVILLE OF THE EASTERN ADIRONDACKS [1]

BY HAROLD L. ALLING

(Read by title before the Geological Society December 27, 1926)

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INTRODUCTION

My first acquaintance with the Adirondack Grenville was through the kindness of Prof. James F. Kemp, under whose guidance in the field, a most delightful experience, I saw the problem of the stratigraphy of this Precambrian series of sediments. It is a problem fraught with many obstacles because of the complex folding [2] of the Grenville, its patchy distribution, injections, and metamorphism. Later I became interested in the Adirondack graphite deposits and studied the Grenville sediments stratigraphically above and below the graphitic quartz schists,[3] which constitute the ore.

In this work I have received valuable assistance from George H. Chadwick, David H. Newland, Wilbur G. Valentine, and Robert J. Howard. In 1917 sufficient field data was at hand to suggest some stratigraphic

[1] Part of the symposium on Precambrian geology.
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Manuscript received by the Secretary of the Society.
[2] H. L. Alling: N. Y. State Mus. Bull. 199, 1917; Am. Jour. Sci. (4), 48, 1919; Am. Jour. Sci. (5), VIII, 1924, pp. 12-32; Econ. Geol., XX, 1925, pp. 336-344.
[3] H. L. Alling: The Adirondack graphite deposits. N. Y. State Mus. Bull. 199, 1917.

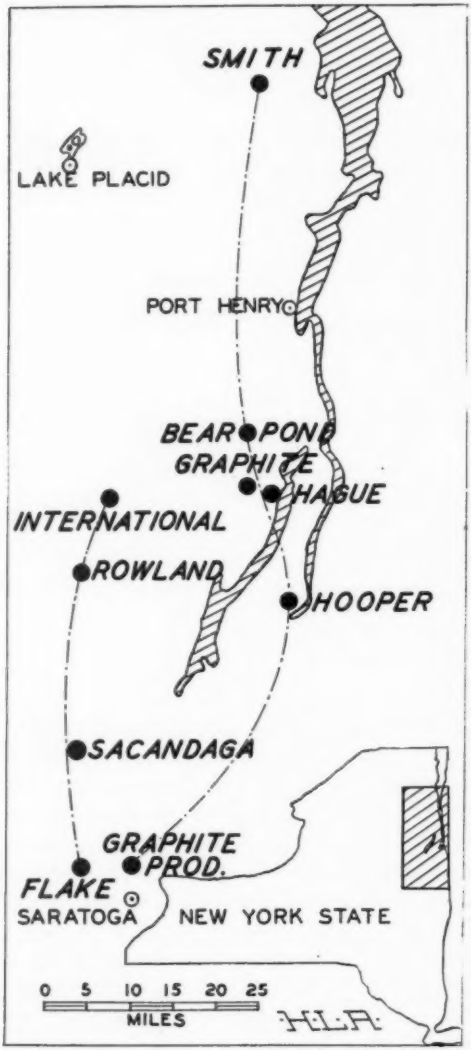

FIGURE 1.—*Sketch Map of the Eastern Adirondacks*

Showing location of the graphite properties where the stratigraphy of the Grenville sediments has been studied. The names of the properties are given in *italics*.

correlations involving a thousand feet of rocks on the eastern Adirondacks. Since then further field studies and a restudy of several hundred petrographic slides justify, I believe, a summary of the problems of the stratigraphy of the Grenville in the eastern Adirondacks with a comparison with those on the western slopes.

THE SECTIONS

Reference to the sketch map (figure 1) will show the location of the ten sections employed in correlation. They are localities where graphite deposits have attracted attention. In most cases the thicknesses of the formations have been secured through plane-table traverses, a method involving much detailed work, as it is not always possible to find outcrops and stadia "shots" for a traverse perpendicular to the strike. The dips, furthermore, are by no means uniform, which complicates the process of securing the thickness of each bed.

The difficulties here encountered, and only partially overcome, compel me to recognize that approximation in many cases can only be claimed. I have appreciated that not all sections have been measured with the same care; hence I attempt to rank the accuracy as follows:

TABLE I

Number	Property	Location	Rank of accuracy
1	Smith graphite property.....	Ausable Quadrangle, Essex County, New York.	B
2	Bear Pond Mountain.....	Paradox Lake Quadrangle, Warren County, New York.	C
3	American Graphite Company, Faxon graphite property.	Paradox Lake and Bolton quadrangles, Hague, Warren County.	B
4	Lake Side Mine, American Graphite Company.	Near shore of Lake George, Hague, Warren County.	A
5	Hooper Brothers.....	Washington County, New York.	C
6	Graphite Products Corporation	Wilton, Saratoga County....	D
7	International Graphite Company.	Chester, Warren County....	D
8	Rowland Graphite Company..	Johnsburg, Warren County..	E
9	Sacandaga Graphite Company.	Day, Saratoga County, New York.	D
10	Flake Graphite Company.....	Greenfield, Saratoga County, New York.	D

BASIS FOR CORRELATION

The Dixon, Faxon, and Hague properties presented the best localities for study. Here the graphitic schist, averaging 15 feet in thickness, is underlain by a highly characteristic formation, 114 to 120 feet thick. It is a bluish green rock with purple garnets as large as peas. In the literature it is called a garnet-sillimanite [para-] gneiss.[4] It is a quartz-feldspar gneiss with garnet and sillimanite. Above the ore there is usually a thin bed of limestone (now marble) which is overlain by a thick quartzitic formation. This succession of beds, easily recognized in the field, was encountered in the majority of graphite localities and constitutes the chief basis for correlation; that is, the garnet-sillimanite gneiss, the graphitic schist, the marble, and the quartzite are here assumed to be the same formations in all the localities. I am inclined to

[4] J. F. Kemp: U. S. Geol. Surv. Bull. 225, 1903, p. 513.
J. F. Kemp and D. H. Newland: 51st Ann. Rept. N. Y. State Mus., vol. ii, 1897, p. 539.

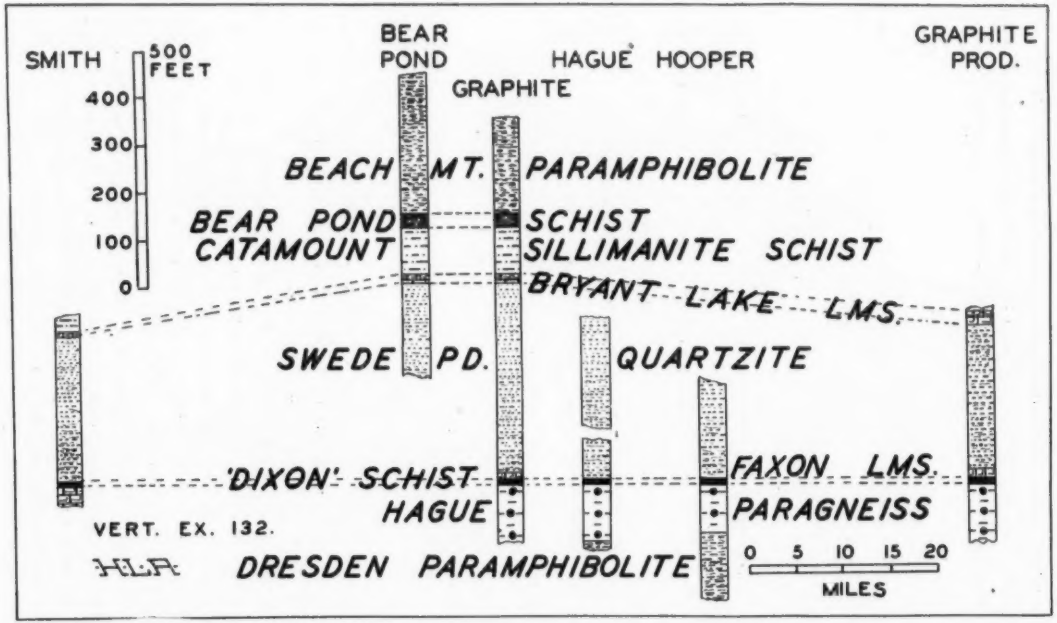

FIGURE 2.—*Correlated Sections of the Grenville Sediments associated with the graphitic Schists in the eastern Adirondacks*
The localities are given at the top of the figure.

believe that this is a fair and safe assumption, although certain facts are difficult to understand on this basis.

General Description of the Formations

1. The Smith area shows a limestone beneath the "Dixon." I have called it the Chesterfield. It is possible that it represents the northern equivalent of the Hague gneiss, or that it is the Johnsburg limestone, with the Hague and Dresden formations cut out by an unconformity. I am inclined to accept the former view.
2. Only two localities, the Bear Pond region and at Graphite, so far studied reveal any higher beds. The Beach Mountain paramphibolite is at least 300 feet thick and is similar to the Dresden formation. Hornblende and plagioclase are the dominant minerals.

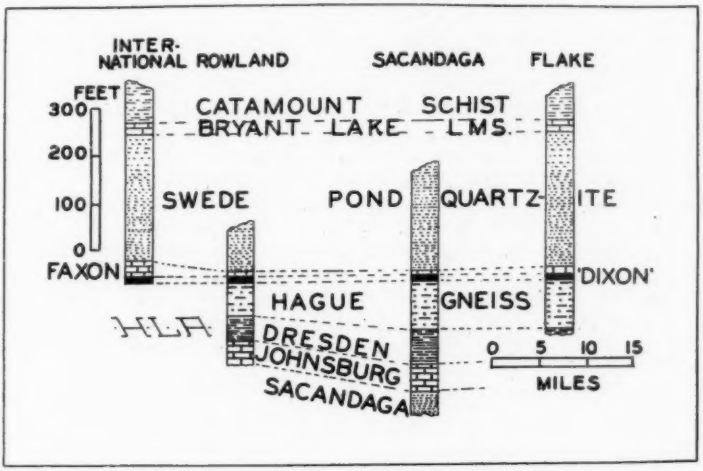

FIGURE 3.—*Correlated Sections of the Grenville Sediments associated with the graphitic Schists in the eastern Adirondacks*

The localites are given at the top of the section.

3. Another graphite-bearing member of the Grenville is next in order. A feldspathic quartz schist with 6 per cent graphite, which has stimulated some prospecting, but is of doubtful commercial value. Perhaps 20 to 30 feet represents its thickness. This is the Bear Pond schist.
4. The Catamount schist, stratigraphically above the Bryant Lake limestone, is a rusty red sillimanite schist. Quartz and feldspar make up a good share of the rock. Certain horizons are low in sillimanite and petrographically are similar to the underlying Swede Pond.

5. Above the Swede Pond is a 20 to 40 foot bed of limestone, here named, for the first time, the Bryant Lake limestone. It is somewhat saccharoidal in the hand specimen, containing considerable quartz, biotite, and feldspar.
6. The Swede Pond quartzite is the thickest unit so far found in the eastern Adirondacks. Generally it contains considerable feldspar and some sillimanite. Certain zones are chiefly of quartz and are glassy in appearance. Four hundred feet have been measured.
7. At seven of the ten localities the "Dixon" is overlain by a relatively thin bed of crystalline limestone named the Faxon. It varies from zero to 20 feet in thickness. It is a siliceous limestone, frequently with titanite grains altered to leucoxene. Biotite, augite, and pyrite occur as accessories.
8. The graphitic schist, provisionally called the "Dixon,"[5] is a feldspathic quartzite with 5 to 7 per cent by weight of graphite. Fifteen feet is an average thickness for the "Dixon."
9. The Hague gneiss, as already noted, is characteristic at the type locality, but varies horizontally more in appearance than in actual composition. It is essentially a feldspathic quartzite, sometimes with garnet and sillimanite, and 120 feet seems to be its maximum thickness.
10. The Dresden paramphibolite is about 120 feet thick and consists of hornblende and plagioclase as principal minerals, with many accessories, including biotite, potash, feldspar, and magnetite.
11. The Johnsburg limestone, named from Johnsburg, Warren County, is a coarse-grained dolomitic marble with serpentinized zones derived from alteration of diopsidic pyroxene. It is estimated to be 30 to 50 feet in thickness.
12. The Sacandaga quartzite is a massive feldspathic quartzite with a few silicate minerals. It is probably more than 50 feet thick; possibly 70 feet. Lower beds have not been seen in the graphite districts.

Variations from Section to Section

General statement

The variations noted in a given formation from section to section are undoubtedly due to many causes: 1. Variations in sedimentation. 2. Subsequent metamorphism. 3. Igneous injection. 4. Surface weathering. To distinguish these factors has proved to be a fascinating problem.

The Hague gneiss

The localities in the easternmost section—Graphite, Hague, and Hooper Brothers—show a rock composed of quartz, microcline, perthite, andesine, sillimanite, and garnet. The Hague gneiss on the Hooper property is lower in garnet, but is more quartzose and contains biotite in addition. All have suffered from igneous soakings chiefly by intro-

[5] This name is preoccupied. See Dixon formation of Tennessee. William F. Pete and R. S. Bassler: U. S. Nat. Mus. Proc., vol. 34, pp. 407-432.

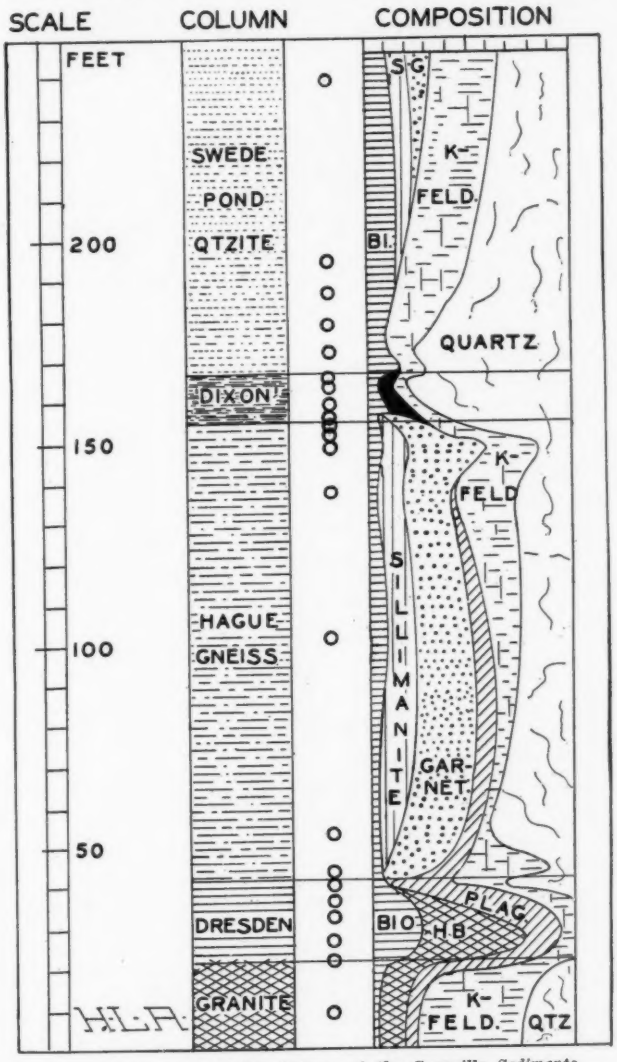

FIGURE 4.—*Stratigraphic Column of the Grenville Sediments*

This column was measured at Hague, the locality of the Lake Side mine of the American Graphite Company. The right-hand column gives the composition in percentage by weight of the rocks as shown by microscopic analyses. The Wentworth recording micrometer stage was used. The position of the circles in the next column to the left shows where specimens were secured for thin-sections.

duction of soda orthoclase and "vein" quartz. The garnet is in part due to reaction brought about by injection. The lower garnet content at the Hooper mine may be due to the greater distance of the "Laurentian" granite.

The Graphite Products Corporation's foot wall contains more garnet and the feldspar is more potassic than the rocks from the above mentioned localities. Igneous activity is much in evidence at this locality. At the Sacandaga pits igneous matters have affected the rocks even more. Here the Hague contains abundant garnet and tourmaline. The feldspathic content has fallen off, with a corresponding rise in quartz. At the Rowland property, near Johnsburg, the Hague is really a quartzite with only a low feldspar content and no sillimanite or garnet. The Flake Graphite district near Saratoga presents a quartz-biotite rock.

If the igneous influences can be discounted, we can draw the conclusion that the Hague formation was more calcareous in the middle eastern Adirondacks and more siliceous in the south. On the Smith area, to the north, occurs the Chesterfield limestone, which, as has been suggested above, may represent the Hague. If so, the calcareous character of the Hague is pronounced in the north. As Kemp noted years ago, the Grenville presents more limestone facies in the western Adirondacks than on the eastern slopes.

THE SWEDE POND FORMATION

This quartzitic formation lacks in most of the exposures examined the garnet of the Hague, even when injected. This would seem to suggest that the garnet in these Grenville beds is largely due to regional metamorphism, but there is local evidence here and there which leads me to believe that there are garnets of other origins. On the Bear Pond Mountain the Swede Pond [6] quartzite, somewhat sillimanite-bearing, has been injected by several intrusions, including a meta-gabbro, which has, if my interpretation is correct, produced a garnet-sillimanite gneiss. Under the microscope the rock could be regarded as a sample of the Hague, but the field relations are positive.

The Swede Pond in the type locality is a normal quartzite with few additional minerals in small amounts. On both Swede Pond Mountain, near Graphite, and the Flake Graphite property, Greenfield, Saratoga County, a zone 10 to 30 feet, 80 feet from the base of Swede Pond quartz, is very glassy. At localities where igneous rocks are more abundant

[6] In 1917 the Swede Pond and the Catamount sillimanite schist were not differentiated in this district. Further studies of the slides and the field maps enable this to be done.

this zone has been injected and magmatically replaced, destroying the glassy character of the rock.

At Hague the upper portions of the Swede Pond are sillimanite-bearing. In the Bear Pond district the Swede Pond is very bountifully supplied with this mineral, and hence the upper Swede at this locality was confused with overlying Catamount some years ago. Farther north the Swede Pond is characteristically sillimanitic and feldspathic. This change in character, quartzose to the south, sillimanitic and feldspathic in the north, is similar to that experienced by the Hague. Clay and calcareous substances seem to predominate in the north.

The other formations have not afforded as much detail and hence horizontal variations are not as yet available.

Metamorphism

All of the Grenville rocks found in the Adirondacks are metamorphosed. It is my opinion that they have experienced several mountain-building periods and were thoroughly foliated when the later intrusives, which I assign wisely or unwisely to the Algoman, entered. There has been considerable magmatic replacement of these beds, but this replacement, or in part assimilation, has often been incomplete and has failed to destroy the structure of the antecedent. Of course, in the marbles, little if any of the previous structures persist. In the quartzitic beds, however, the syntectic character of much of the Grenville is evident.

The units here discussed are syntectics in many places. How successful I have been in distinguishing sedimentary originals from igneous replacements, no one knows. Petrographic interpretations must be controlled with this idea as a working principle. This idea has made it possible to identify Grenville sediments, even when they are much involved with intrusives, when formerly they were regarded as "gneisses of unknown origin." In some of the districts Grenville sediments are comparatively free from igneous materials at one place, but show much magmatic replacement a thousand feet away. Such exposures, when carefully measured, show that little or no change in volume has occurred when they were lit-par-lit injected and partially replaced.

The foliation of the Grenville is not solely that of the bedding planes. Secondary foliation can be definitely identified. At some localities the magmatic fluids have followed old bedding planes and at other places secondary foliation.

Much of the foliation of the intrusives underlying blocks of "floating" Grenville sediments is due, in my opinion, to the superposition of the

structure of the Grenville on the intrusives; that is, much of the *structure* of these syntectic gneisses is of *sedimentary origin,* while the *rocks* are chiefly of *igneous origin.* These orthogneisses exhibit cataclastic and protoclastic structures, frequently distinguishable; but I believe that some of the protoclastic banding is due to gneissoidal flowage controlled by the Grenville structure.

Summary

The portion of the Adirondack Grenville shown in the correlated sections accompanying this paper is a relatively small one; neither the top nor the bottom has been recognized. It is extremely doubtful if they ever will be found. Through plane-table traverses and detail petrographic studies, the folds, faults, and magmatic replacement, to a considerable extent, can be ruled out.

This portion of the Grenville seems to show an increasing calcareous content to the north and to an even greater degree to the west. This confirms Kemp's opinion of many years ago.

Magmatic replacement following lit-par-lit injection as a phase of assimilation is not usually emphasized. This process does not seem to have affected the volume or thickness of the sediments. The foliation of the Grenville is of several origins. Besides the bedding planes, there is foliation of secondary origin of several distinct ages. The foliation of the igneous rocks beneath Grenville cover is regarded as due to superimposition.

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PRECAMBRIAN ROCKS OF THE UNION OF SOUTH AFRICA[1]

BY ARTHUR W. ROGERS

(Read before the Geological Society December 27, 1926)

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INTRODUCTION

As a Cambrian fauna has not been found in South Africa, where the oldest known fauna is of Devonian age and occurs in beds some 5,000 feet above an unconformity of great importance in the structure of the southern part of the subcontinent, the upper limit of the Precambrian is chosen arbitrarily.

In the literature such terms as Silurian, Ordovician, Cambrian are to be found, but their use is unwarranted, for no fossils from the rocks so designated have been described or determined.

TABLE MOUNTAIN SERIES AND WATERBERG SYSTEM

The most important difference of opinion concerning the intercorrelation of South African rocks affecting this question is about the contemporaneity or otherwise of the Table Mountain series in the south and the Waterberg system in the north. In this article the assumptions will be made that these formations are of different ages, and that the Waterberg system is the older and is of Precambrian date. For the first

[1] Part of the symposium on Precambrian geology.

assumption there is evidence from the comparison of the structure of the Southern Cape Province and that of Griqualand West and the Transvaal; in the south of the Cape Province the Table Mountain series is at the base of a great group of conformable sediments, including Karroo beds, which are affected by the late Karroo earth movements; in the northern districts the basal Karroo beds rest on folded and greatly denuded Waterberg rocks. Opinions differ as to the weight to be given to this structural evidence. For the assumption that the Waterberg system is of Precambrian age there is no decisive evidence; the formation appears to be unfossiliferous and is of pre-Devonian age. It will be included in this article because it is one of the important ancient systems and may be Precambrian.

The igneous Rocks

In South Africa there is no mass of granite, gneiss, or other rock of igneous origin proved to be older than the most ancient sedimentary and volcanic rocks recognizable as such by petrographic characters and mineral composition. The most ancient masses of granitic rocks are those in the northern and eastern Transvaal, Swaziland, Zululand and Natal, and the northwestern and northern districts of the Cape. Though these most ancient igneous rocks are for the most part known in little more than outline, they all include important bodies of more or less highly metamorphosed sedimentary beds and, in several instances, of volcanic rocks also. The altered sediments appear to predominate. In Namaqualand the remnants of the oldest sediments and volcanics appear to be of small extent, but the region is very imperfectly known. Farther west, in Kenhardt and Prieska, what is believed to be the same mass of granitic gneiss is in intrusive contact with large bodies of sediments and volcanics, the Kheis series, composed, from above downward, of the Wilgenhout drift, Kaaien, and Marydale beds. Many fragments of the two lower of these groups have been recorded lying in gneiss detached from the main body.

The Marydale beds include limestone, chert, arkose, quartzites, magnetic quartzites, as well as altered rhyolitic and basaltic lavas; the whole thickness may not exceed 1,500 feet. The lavas are often amygdaloidal, and it was the persistence of the amygdules in the slightly altered rocks and in the dark hornblende schists and typical granulites that enabled the latter to be recognized as of volcanic origin.

The Kaaien beds are mainly quartzitic, but quartz schists are abundant and magnetite quartzites occur. With this group and the Marydale beds,

pale granulites are often closely associated and their origin is obscure. They range in composition and structure from schistose gneiss and granulites with equidimensional grains to felspathic quartz schist and quartzite, while cyanite, staurolite, and sillimanite are occasional constituents. No doubt some of these rocks are altered sediments, but the presence of remains of an old gneissic floor on which the Kheis beds were deposited may be suspected. The thickness of the Kaaien beds is considerable, but it has not been determined.

The Wilgenhout drift beds overlie the Kaaien and consist of slates, acid and basic lavas and tuffs, conglomerates, quartzites, probably magnetic quartzites, and limestones. The beds are in all more than 6,000 feet thick.

The Kheis series as here described is over 120 miles distant from the westernmost known outcrops of another ancient group, the Kraaipan series, recognized in Bechuanaland and the western Transvaal. The Kraaipan rocks are at least 10,000 feet thick and consist of banded magnetic quartzites, cherts, jaspers, chlorite schists, and other slaty rocks, calcareous schists, quartz-porphyry, and schistose volcanic rocks. Up to the present these rocks are not known to be invaded by gneiss, from which they are in places separated by faults.

As yet there is no means of determining the relative ages of the gneiss and granite of Bechuanaland, which contain large fragments of altered sediments and igneous rocks, and the gneiss of Kenhardt and Prieska which invades the Kheis series. Appearances suggest that the Bechuanaland gneiss is the older, and that the Kraaipan series may be the northern equivalent of the Kheis.

The Moodies and Pongola Series

Similar difficulties obscure the relation of the Kraaipan series to the Moodies and Pongola series and to the great masses of altered sediments lying in the gneiss of the Limpopo Valley north of the Zoutpansberg.

Moodies series is the name given to a thick series of conglomerates, slates, quartzites, and banded ironstones in the Barberton and Pietersburg districts. They are older than the neighboring gneiss. Apparently overlying the Moodies series, but also older than the gneiss, is the Onverwacht volcanic series, basic and acid lavas and tuffs; perhaps also altered dolomites. Another group, the Jamestown series, of basic schists, often intrusive, with belts of altered sediments and lavas, accompanies the Moodies series in Barberton.

The Pongola series is made up of rocks which are almost certainly to

be correlated with Moodies and the Onverwacht beds; they occur in Piet Retief, Swaziland, and Zululand. The Lower Pongola consist of three groups of quartzites and slates, about 1,000 feet in each instance, overlain by three groups of andesitic lavas, each group being from 2,000 to 3,000 feet thick. The Upper Pongola beds are some 8,000 feet of slates, quartzites (with subordinate conglomerates), magnetic ironstones, and jaspilites.

Swaziland System

The name Swaziland system has been given to those South African rocks older than the gneiss in their neighborhood, or, as in the case of the Kraaipan series, believed to be the correlatives of such rocks. Thus the Onverwacht, Jamestown, Moodies, Pongola, Kheis, Kraaipan, and the older schists in Namaqualand, Limpopo Valley, and Natal are all included in this "system"; and in Prieska, Bechuanaland, the western and the southern Transvaal, the gneiss is older than the Witwatersrand and Ventersdorp systems, while in Namaqualand it is older than the Nama system, and in the Eastern Transvaal older than the correlated Transvaal system.

A general feature in all these rocks included in the Swaziland system is the presence of most types of sediments together with banded ironstones. Volcanic rocks, both lavas and tuffs, are prominent, but they form a less important part of any one of the formations mentioned than they take in the later Ventersdorp system. It is worth noting that no rocks for which a glacial origin has been suggested have been found in these formations.

Unconformity at Base of Witwatersrand and Ventersdorp Systems

We now reach a marked unconformity at the base of the Witwatersrand and Ventersdorp systems. These two groups are closely associated in the southern Transvaal, where the Witwatersrand beds are conformably overlain by the Ventersdorp south of Johannesburg and unconformably overlapped by them to the north and west. Except for the economic importance of the gold-bearing conglomerates in the Witwatersrand group, it would very probably have been placed in one "system" with the Ventersdorp group. The detrital sediments of the Witwatersrand system are continental deposits, probably of deltaic origin, and they include no limestones, though banded ironstones in which no evidence of the former presence of carbonates has yet been recorded are a conspicuous but minor feature.

A glacial origin has been claimed for some 25 feet of boulder and pebble-bearing mudstone succeeded by finely banded ferruginous shales in the Government Reef series in the Heidelberg and Klerksdorp areas.

Intercalations of volcanic rocks occur in the Witwatersrand beds, and the latter are succeeded by the thickest group of lavas, less basic than olivine basalts, known in South Africa. These lavas are part of the Ventersdorp system, which, in the Cape Province, is divided into three subgroups by unconformities:

1. The lowest subgroup, the Zoetlief series, reached a thickness of 1,300 feet at Kimberley, and consists of rhyolitic lavas with subordinate breccias, conglomerates, quartzites, and arkose.

2. The Kuip series, some 1,500 feet of basic and intermediate lavas, with beds of arkose, grits, flagstones, sandstones, limestones, and cherts, have been recognized over a small area in Prieska only, but they are a group separated by unconformities from the Zoetlief beds below and the Pniel above.

3. The Pniel series is the thickest and most extensive of the three series in the Cape Province; it consists of conglomerates, quartzites, limestones, and cherts, over 700 feet thick in all, followed by at least 1,600 feet of lavas and breccias of intermediate and basic composition.

In the Transvaal the Ventersdorp system has not yet been subdivided into series corresponding to those described above.

4. The Witwatersrand beds on the Rand and in Heidelberg are succeeded by at least 5,000 feet of lavas, and these again by sediments and more acid lavas. In the Ventersdorp-Klerksdorp region conglomerates and other sediments are greatly developed.

The Witwatersrand-Ventersdorp rocks represent a period of considerable diastrophism, during which volcanic activity became greater and possibly more general as time went on. The unconformity separating the Ventersdorp from the Transvaal system is constant in the regions where the two are found, but in the Vryburg and Mafeking districts lavas of the more basic Pniel type lie between the Black Reef series and the overlying dolomite, pointing to the long persistence of the volcanic activity.

According to our present information, Witwatersrand beds are known only in the southern Transvaal and the neighboring part of the Orange Free State. The Ventersdorp beds extend 120 miles to the north and 430 miles to the southwest of the Witwatersrand itself; they are not known in the eastern Transvaal, but they may be represented by the Konkip formation in Southwest Africa.

Correlation of the Transvaal and the Nama Systems

The Transvaal system is, with a considerable degree of confidence, correlated with the Nama system of the west and south, though the nearest outcrops of the two are 130 miles apart. It consists broadly of three members. The lowest is mainly arenaceous (Black Reef, Nieuwerust, Kuibis, and Stinkfontein series), ranging from a few feet up to 2,500 feet in the northeastern Transvaal. The next is the great dolomitic formation in South Africa, known as the Campbell Rand, Otavi, Kaigas, or Malmesbury series in different parts and becoming a mainly argillaceous formation in the southwest of the Cape Province. Its maximum thickness is believed to be some 3,500 feet.

The highest subgroup is known as the Pretoria, Ibiquas, and Numees series, in the northern and western regions respectively. It is composed of argillaceous and quartzitic beds, with a minor volcanic group (Ongeluk series), and an extensive tillite has been recognized in Griqualand West, the Transvaal, and Namaqualand; probably also in Oudtshoorn, where the Congo series probably represents more than one series of the Nama system.

It is very probable that an unconformity of variable, but slight importance in the Transvaal, becomes pronounced in the west and south of the subcontinent. The Nama or Transvaal system has a greater extent than any South African formation except the Karroo system.

The Bushveld Igneous Complex

The deposition of the sediments of the Transvaal system was brought to an end in the Transvaal through the region becoming the scene of an outpouring of felsitic magma, the earliest recorded event in the long sequence of igneous activity which gave rise to the Bushveld Igneous Complex. These felsites form the greater part of the Rooiberg series and are accompanied by breccias and also shales and sandstones. Whether the Rooiberg series should be regarded as the youngest part of the Pretoria series or left as an independent and the uppermost series of the Transvaal system is a point on which opinions have not yet agreed.

The Bushveld Igneous Complex has at present no recognized counterpart in the west and south of the subcontinent, but in those areas invasion by granitic magma on an extensive scale occurred after the deposition of at least part of the sedimentary and volcanic rocks included in the Nama system.

The Transvaal-Nama Unconformity

A great unconformity separates the Transvaal and Nama formations from younger sediments. In the north (Transvaal and Griqualand West) a great group of arenaceous beds with minor argillaceous and volcanic rocks, known as the Waterberg system (including the Matsap formation), closes the presumably pre-Paleozoic record. The Waterberg beds are generally red or purplish in color and are not known to be accompanied by limestones; their thickness amounts to 7,000 feet or more. Observers have remarked on their lithologic resemblance to both the Torridonian and Old Red Sandstone formations of Scotland.

Igneous Activity

Igneous activity on a great scale is recorded by pre-Nama (and also probably pre-Witwatersrand) gneiss and granite in the east, north, and west of the subcontinent, and the comparison of the structure of the country occupied by the Kheis and Kraaipan formations suggests two such periods of activity. Post-Nama intrusions of granitic magma produced the Cape granite and gneiss, a large mass of granite in Namaqualand, and the Bushveld complex.

As regards the intensity of volcanic activity, the evidence does not suggest that the Precambrian manifestations in South Africa were of greater extent or gave rise to markedly greater piles of lava-flows than the vulcanism of late Karroo (that is, late Triassic or early Jurassic) age.

Correlation Table

Transvaal.				*Other parts of South Africa.*
Waterberg system.		Continental arenaceous deposits, lavas and tuffs, over 7,000 feet.		Matsap series.
	(Unconformity.)			
Transvaal system.	Rooiberg series	Felsites and sedimentaries, 2,000 feet.		
	Pretoria series.	Argillaceous, arenaceous, and volcanic tillite, 10,000 feet.	Nama system.	Ibiquas and Numees beds.
	Campbell Rand series.	Dolomitic limestones and shales, 3,500 feet.		Malmesbury and Kaigas beds.
	Black Reef series.	Arenaceous, minor volcanics, 2,500 feet.		Nieuwerust and Stinkfontein beds.
	(Unconformity.)			
Ventersdorp system.	10,000 feet.	Lavas, tuffs, and sediments.		Pniel series.
		Lavas, tuffs, and sediments.		Kuip series.
		Acid lavas and sediments.		Zoetlief series (Koras series of Orange Valley and Konkip of Southwest Africa).
	(Unconformity in part.)			
Witwatersrand system, 24,000 feet.	Kimberley-Elsburg.	Quartzites, conglomerates, and shales.		
	Main-Bird series.	Quartzites, conglomerates, shales, and lava.		
	Jeppestown series.	Chiefly shales.		
	Government Reef series.	Quartzites, conglomerates, shales, banded ironstones, and a tillite.		
	Hospital Hill series.	Quartzites, shales, ironstone.		
	(Unconformity.)			
Swaziland system.	Upper Pongola.	Moodies series.		
		Onverwacht series.		
	Lower Pongola.	Jamestown series.		
(Intercorrelation uncertain.)	Abels Kop beds.			Kraaipan series.
		Wilgenhout drift beds.		Kheis series.
		Kaaien beds.		
		Marydale beds.		
Various schists in the Limpopo Valley, Namaqualand, Natal.				

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PRECAMBRIAN OF FENNOSCANDIA, WITH SPECIAL REFERENCE TO FINLAND[1]

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(Read before the Geological Society December 27, 1926)

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INTRODUCTION

In those regions in northern Europe where Precambrian rocks prevail—that is, in the territory which comprises great parts of Scandinavia, all of Finland, Russian Carelia, and the Peninsula of Kola, and which is now generally called Fennoscandia—the main interest of the geologists study-

[1] Part of the symposium on Precambrian geology.

Various schists in the Limpopo Valley, Namaqualand, Natal.
Marydale beds.

ing the Precambrian rocks has long been focussed on the investigation of the older, crystalline parts of this complex; consequently, mainly petrological methods have been used. These rocks are here also the richest ore-bearers, not, as in North America, the rocks of Proterozoic or Huronian type. Rocks similar to the latter, for the study of which stratigraphical methods are applicable, are also found, however, in Fennoscandia, in its eastern and northern parts, where especially Finnish geologists have studied them, and also on the Russian side of the boundary. The central position of Finland and the circumstance that it is here that the sedimentary formations in question show the greatest continuity, has caused the geologists of Finland to be most anxious to arrive at a correlation of the Precambrian rocks of all Fennoscandia, which no doubt form one continuous area. However, the rock formations present a very varying aspect in different parts of this territory, and those formations that give the clue to the proper understanding of its Precambrian geology lie now in one, now in another, of the countries constituting it.

A great difficulty in the investigation of this area has been the necessity to do simultaneously the detailed mapping and the development of the theoretical conceptions on which it should be based; but this difficulty is, after all, common to all geological mapping, especially in crystalline areas. The surveying should, therefore, be done repeatedly, at least in the most important "clue regions," till we arrive at somewhat more definite results.

The main features of the Fennoscandian Precambrian area are shown by the sketch map in figure 1. As seen from it, the territory may be roughly subdivided into three parts:

The east and west areas, where gneissose granites prevail and sedimentary formations occur only in lesser extension, and the central area, the *"Midgard zone,"* which has a very varying composition.

The chronological subdivision of the rocks of this complex which the writer has tried to arrive at, taking advantage of the work of numerous collaborators, has been mainly based on the relations of the sedimentary and effusive (in one word, supercrustal) formations to the widely distributed granites, which indicate periods of diastrophism which have each time acted on great areas of the territory in question.

This does not mean that only the granites have been used for working out the succession. Such sedimentary formations as have a wide distribution or present characteristic peculiarities have been used as well for determining the age; also that of the granites. In general, the rela-

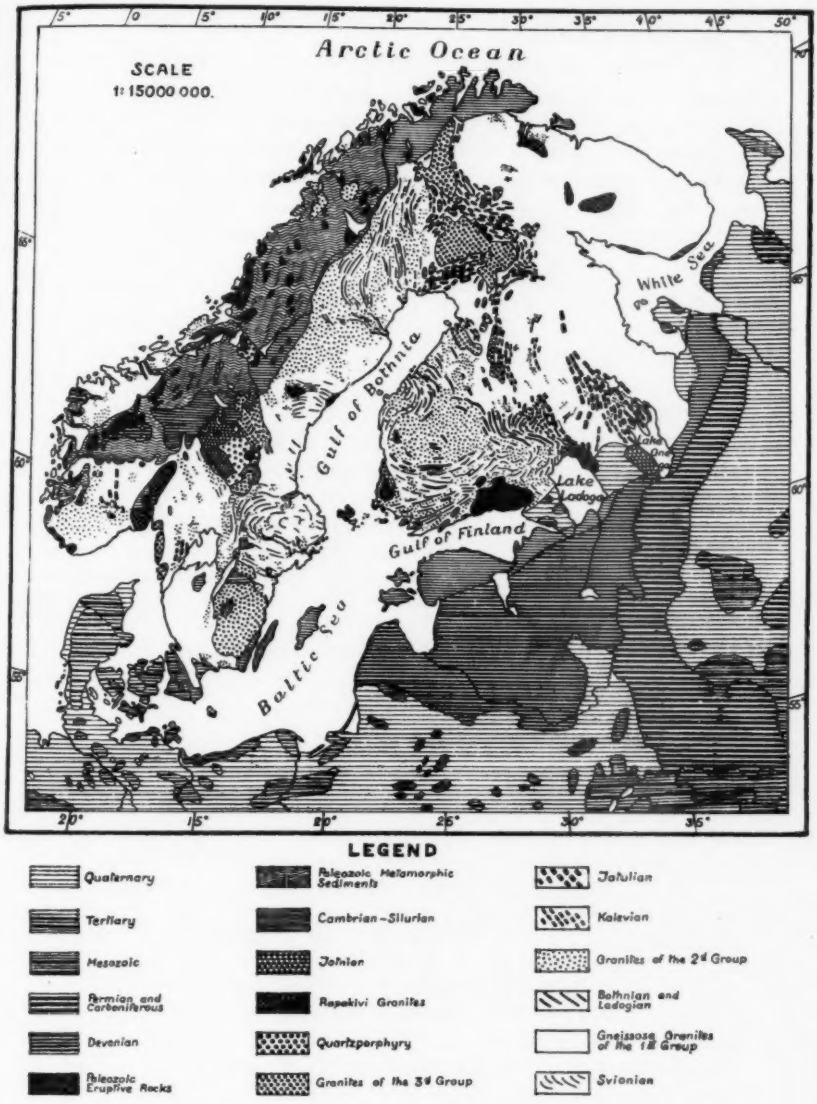

FIGURE 1.—*Geological Sketch Map of Fennoscandia and adjacent Region*

tions of all rocks to each other have been studied, especially with the aid of their contact relations.

As a result of the work of the Geological Survey of Finland, we have been able to discriminate between four great groups of granites, of which the second may probably be subdivided into two or more minor groups.

Between the eruptions of these granites periods of calm have intervened, during which erosion, peneplanation, and sedimentation have been going on.

In this way we arrive at the following classification:

GENERAL SUBDIVISION OF THE PRECAMBRIAN ROCKS OF FENNOSCANDIA

Upper Proterozoic (Formations of Keweenawan type)	Jotnian
	Unconformity
	4. Granites of the fourth group = rapakivi granites, with effusive equivalents
	Great unconformity
Lower Proterozoic (Formations of Huronian type)	3. Granites of the third group (including post-Kalevian granites), with effusive equivalents
	Jatulian and Kalevian
	Great unconformity
Upper Archean	2. Granites of the second group (post-Bothnian granites, etcetera)
	Bothnian $\gtrless$ Ladogian
	Unconformity
Lower Archean	1. Oldest gneissose (= Katarchean) granites = Leptite formation
	Basement unknown

Classification of the Granites of Fennoscandia

Granites of the fourth group—Rapakivi granites

The youngest granites, belonging to the latest, or fourth, group, are the so-called Rapakivi granites, peculiar red porphyritic granites rich in potash. The rounded orthoclase crystals often show a covering of oligoclase. These granites pass by gradations into granite porphyries and quartz porphyries; also into such forming effusive beds. They are almost completely devoid of any signs of metamorphic changes, and gneissose texture or "stretching" is also practically absent.

These granites occur in rounded areas with sharply defined boundaries, the greatest measuring about 700 square miles. They cut all the surrounding rocks of Archean or Lower Proterozoic age, thus being decidedly younger than all of them. Among Precambrian rocks only the Jotnian sandstones and the olivine diabases intercalated with them are younger than the Rapakivi. Further, Cambrian and Ordovician rocks have been shown to lie directly on Rapakivi granites, thus determining their Precambrian age with full certainty.

As these granites show practically only primary features, originated by the solidification in one casting of a granitic magma, their study gives the clue to the understanding of the primary textures also of the older granites.

Granites of the third group, including post-Kalevian granites

The granites of the third group, which are next older than the Rapakivi granites, still show many similarities to these rocks. They also often form, especially in southern Finland, well defined, commonly rounded areas, and show themselves there as decidedly younger than all surrounding Archean rocks, especially, also, those of the preceding, second group. Some of them are almost as little metamorphic as the Rapakivi granites, but mostly they show an unmistakable, although feeble, influence of changing (in this case autometamorphic) agencies. Sometimes they may even show stretching or gneissose structure, although generally in no very strong degree.

In southern Sweden granites of this type are associated with feebly metamorphic meta-rhyolites and tuffs, showing that the granitic magma has reached to the surface. In northern Fennoscandia similar granites, which are younger than the two older groups of granites of Archean type, have a wide distribution. Here sedimentary formations exist which are intermediate in age between these granites of the third group and those belonging to the preceding second group.

Chemically these granites are often rather similar to the Rapakivi rocks, but show a somewhat greater variation, passing by gradations also into dioritic rocks. Lamprophyric dikes occur in genetical association with these granites and are then older than their last aplitic veins.

When found in areas of wide extent, these granites show many of the features which characterize Archean granites, but when found in smaller areas, and in places where they have reached near to the surface, they resemble more the post-Archean Rapakivi granites. Some of the rocks of the small outcrops have even been mistaken for Rapakivi granites, but later contacts have been found which have placed their difference beyond doubt. Now there seems to be general agreement that the peculiarities of the Rapakivi granites are so characteristic that they allow of determining their age with certainty now, on petrological grounds. At least there is no dissension about the age of any granite of this latest group.

Although occurring in different and distant parts of Fennoscandia, the granites of the third group have a decidedly restricted distribution. They do not interweave as veins rocks lying very far from their typical areas.

GRANITES OF THE SECOND GROUP—POST-BOTHNIAN AND BOTHNIAN GRANITES

The granites of the second group have a still greater extension, especially in middle and southern Finland, and often form less distinctly separated areas, also interweaving as veins some rock masses very far from the greater outcrops. They show a greater variety as to texture and composition than the granites of the later groups. Equigranular rocks prevail, but porphyritic varieties also exist. Pegmatites are very common and abundant. Together with the prevalent varieties, rich in microcline and mostly reddish in color, some gray and richer in plagioclase also occur and pass by gradations into granodioritic, dioritic, and even more basic rocks.

These granites are only in exceptional cases connected with quartz porphyries. In general they possess a typically plutonic character and seem to form real batholiths. Their detailed study, especially in southern Finland, has shown that they have not only broken through the older rocks, but also penetrated them very intimately, soaking them with their magma or emanations from it, so that the older rocks have been gradually changed *in situ* into the younger granites. A great part of the granites in question are, because of this assimilation with older rocks, "*migmatitic*" in character. In many instances they are quite massive

("homophanous"), however, especially in the great granitic area of Finland, and possess rather characteristic features.

Geologically, these granites are characterized by the fact that they are older than the Kalevian and Jatulian rocks and younger than the Bothnian, which they everywhere penetrate. They have, therefore, in Finland, generally been designated as post-Bothnian granites.

Now there are, intercalated with the Bothnian schists or forming pebbles in their conglomerates, also effusive rocks of syenitic and granitic composition, connected by gradations with hypabyssal rocks of similar composition. Thus there seem to exist granites that are not post-Bothnian, but Bothnian in age. The Bothnian was in general a period of turbulent eruptive activity.

But also among these granites which certainly penetrate the Bothnian schists there seem to exist groups of somewhat different age. Some of them have possibly been intruded between the layers when they were still nearly horizontal, and have been upturned to a vertical position together with the schists, whereby they became gneissose. Varieties of these granites may also have originated by the "refusion," or anatexis, of the oldest gneissose granites. In any case these gneissose granites of post-Bothnian age are often rather well separated from the massive varieties which occur, for example, in the central area of these granites.

In northern Sweden we find, in the Skellefteå area, granites which seem to belong to the second group, but which, however, form the basement of certain conglomerates which are penetrated by the granites of the main group of post-Bothnian granites.

Thus there seem to be definite proofs of the fact that the second group contains genetically different formations.

As to the discrimination between the granites of the second and the third group, it is easy to distinguish them when there are, as is the case in eastern and northern Finland, sedimentary formations "sandwiched in" between them, or when the former has, as is the case in southern Finland, a regional distribution and the latter forms isolated areas whose boundaries cut the boundaries between the older rocks. Where both granites occur in separated areas, it will be more difficult to distinguish them. In Sweden these two groups are generally reckoned as one, sediments of intermediate age existing only in the northernmost regions, which have not been mapped in great detail.

GRANITES OF THE FIRST GROUP—OLDEST GNEISSOSE ("KATARCHEAN") GRANITES

The oldest granites, belonging to the first group, are, as a general rule, gneissose in texture. They commonly show a more or less distinct

foliation; but also, when this is absent or indistinct, their minerals are strongly crushed or granulated, as usual in gneissose granites. These rocks are more often plagioclase granites than rich in microcline, and they often pass into dioritic and gabbroid varieties. Quartzporphyritic varieties also occur in the regions where supercrustal schists are common.

This formation of granites has the greatest extension. It is possible that it comprises things which are genetically different, although possessing the same general character, but it has thus far not been possible further to subdivide this great group of granites.

Geologically it is characteristic of it that it forms the basement of all Precambrian sedimentary schists, besides the oldest "leptite formation."

These oldest granites differ from all others both by their, in the main, uniformly gneissose character and their almost ubiquitous extension. They have in fact been referred by several authors to the "first solidified earth's crust." Partly under the assumption that the gneissose granites of eastern Finland are older than all normal sediments, the present writer has designated them as "Katarchean" granites. As, however, it has become quite clear that at least a great part of the oldest granitic gneisses penetrate the supercrustal rocks, among them also mica schists, belonging to the "leptite formation," in the same way as later granites do, they can only be regarded as belonging to the first crust, if also these supercrustal rocks are reckoned to belong to it—that is, believed to have originated under identical exceptional circumstances at the dawn of geological history. In any case, these granites may be designated as "crustal" because they extend over great areas and probably continue to very great depths.

Significance of the parallel Texture of the Granites

As the youngest of these granitic formations is entirely massive ("homophanous") and the older become more and more gneissic, on the whole, in proportion to their age, it has been assumed that they form a series of gradually increasing dynamometamorphism. The older should have taken part in the greatest number of mountain-making movements, while the youngest should not have been affected by any of them.

A closer study of the gneissose granites, especially at the southern coast of Finland, has, however, led the writer to another opinion.

A great part of the parallel texture of the granites is due to the assimilation of older schistose rocks. Even the Rapakivi, the very type of a massive granite, may thus, in exceptional cases and in the smallest possible measure, become striped next to the contacts. In the third group

this phenomenon is already more common, and the granites of the second group are, as a rule, over large areas—for example, in territory along the southern coast of Finland—never entirely homogeneous, but always more or less "migmatitic," and then also not seldom gneissose in character.

In other cases the foliation is due to movements that have taken place in the granitic masses before their final solidification. True protoclastic movements seem, however, not to have played such an important rôle as movements at an epoch when great parts of the granite were already almost completely solidified and thus able to be crushed, but before the time when the last portions of the same magma solidified. This assumption is proven by the fact that the foliation is in some cases cut by lamprophyric and pegmatitic veins which indubitably belong to the same magma, and that it has always originated before the time when the next succeeding supercrustal formation was deposited. Gneissose pebbles occur in their conglomerates, and the foliation of the granites is cut by dikes connected with the overlying effusive rocks. It is thus impossible to think that it could have originated during an orogenetic period later than the deposition of the younger sediments.

The writer has found that the formation of the foliæ of mica, giving to the gneissose granites their parallel texture, is in certain cases contemporaneous with the origin of lamprophyric dikes occurring in the same granites. These have also been formed by the accumulation of the femic constituents along certain disclocation planes at a time prior to or contemporaneous with the solidification of the last aplitic "juices."

Although the explanation of the gneissose texture has thus changed, the fact remains that the older granites are comparatively more gneissose than the younger, and this character may thus be used, although with caution, as a criterion for determining the age of the different granites.

By using all the criteria at hand, it will often be possible with certainty to distinguish the different granites already from their petrological characters. In the region at the southern coast of Finland which the writer has studied most closely, all the four groups of granite occur, and in most cases it is possible to say with certainty to which group each outcrop and even each individual dike or vein belongs. However, the deciding criterion is, of course, their contact relations with other rocks of known age.

In general, the greatest difficulty has been the distinction between the oldest gneissose granites and the gneissose varieties of the granites of

the second group, and in some regions also, as already said, the discrimination between granites of the second and third group.

Palingenesis and "subcrustal Unconformities"

The fact, proved by the present writer, that certain granites may, under the influence of ultrametamorphic agencies ("anatexis") be changed *in situ* into rocks behaving as if they were younger than rocks which had earlier penetrated them or been deposited on them, may cause a certain difficulty in the determination of the age of the different granites. Practically, however, every granite which has become palingenetic at a certain period ought to be regarded as geologically of that age. Of course, the insidious transitions between older and younger granites will make some difficulties.

The writer has also assumed that there might be cases where the last portions of the granites of one group, whose solidification has very long continued at great depth, may be of the same age as granites of a later group. There would thus exist a "subcrustal unconformity" between both of them.

This idea, however, ought to be applied with great caution. In most cases the writer and his collaborators have found, when investigating the granitic formations of Fennoscandia, that it is possible rather definitely to subdivide these into groups of different ages, and the character of the sedimentary formations intermediate in age seems also to indicate that the calm between the periods of disastrophism and granitizations has been rather complete.

The Archean of Southwestern Finland and the Question of its Divisibility

Leptite formation (Svionian)

As already said, there are supercrustal rocks which are certainly older than the gneissose granites of the first group and which, no doubt, belong to the oldest surface formations observed anywhere on our globe.

These are the "leptites," which have such a wide distribution over great parts of Sweden, where they contain its most valuable ores, and in southern Finland. They are feldspathic schistose rocks of very varying origin. Some are certainly tuffs, associated with effusive metarhyolitic, metaandesitic, and metabasaltic rocks; others are metapelites or metamorphic graywackes. In some cases the leptites have a very peculiar composition, containing up to 12 per cent of potash. Crystalline limestones also occur

in great quantities, and in the upper parts of this formation also true quartzites occur. Conglomerates are not entirely wanting.

This formation has in Sweden often been regarded from an antiuniformitarian point of view. Where we find these rocks well preserved, we meet, however, in most cases features which are not very different from those of younger supercrustal rocks. Even in areas where they are ultrametamorphic and have been soaked with granite, they may occasionally show a regularity of the geological structure which is astonishing. Their difference from other formations of sedimentary schists seems to the present writer largely to be due to the circumstance that they have taken part in the very strong orogenetic movements which have taken place at the eruptions of the Archean granites and also in the diastrophism connected with the eruption of the granites of the second group. Thereby the schists have been much changed mechanically and chemically and often mixed up with veins of this granite.

Geologically the age of this formation, which the writer has proposed to call *Svionian* (Svionii: svear, inhabitants of Svealand = middle Sweden), is determined by its relation to the gneissose granites which always penetrate its rocks.

The strike of the zone of these rocks, which stretches from middle Sweden over southern Finland (*Sveco-Fennian zone*), and remnants of which still occur, although partly assimilated by the gneissose granite of eastern Finland and Russian Carelia, is preponderantly in northeast or east-northeast. This seems to be the direction of the oldest mountain chains known to have existed.

BOTHNIAN FORMATION

The question has long been mooted whether there exist, in southwestern Finland or elsewhere, any supercrustal formations separated by an unconformity from the oldest "leptite" formation. As to Sweden, the answer has in general been in the negative. In fact, most of that country's Archean schists of supercrustal origin belong to the leptite formation and are older than the oldest gneissose granites, with the exception, perhaps, of a few areas north and northeast of Lake Wenern, of some metabasaltic rocks occurring mainly as dikes in the region north of Stockholm, and of some schists in the Loos and Skellefteå regions in northern Sweden.

It is no wonder that many geologists of Sweden have been inclined to deny also the divisibility of the Archean of southwestern Finland, the more so as it has been very difficult to get quite definite proofs of it.

In the nineties the present writer described, from southwestern Finland, schists which comprised, on the one hand, effusive volcanic rocks with extremely well preserved minute volcanic textures; on the other hand, sediments with an astonishingly modern appearance—metamorphic clays showing the same regular alternation of different layers ("varves") as is characteristic of modern glacial clays, conglomerates, stratified tuffs, etcetera. The metapelites contain at some places structures which the writer has interpreted as fossils (*Corycium enigmaticum*), an opinion which has been shared by some paleontologists of renown, while others have been doubtful.

These zones of schists occur mainly at the southern boundary of the great central granitic area. The strata of the schists are vertical, but the orientation of the "varves" shows that the basement lies at the southern side, where strongly metamorphic veined gneisses and gneissose granites prevail. At some places conglomerates exist at the borderline.

The writer thought that both the veined gneisses and the gneissose granites belonged to the basement of the less metamorphic schists, which he called "Bothnian." He correlated the metabasaltic tuffs occurring in their upper division with the metabasaltic rocks outcropping more to the south.

Some apparently intrusive contacts between the Bothnian schists and porphyritic gneissose granites were interpreted as being due to tectonical movements. Later, however, a more detailed study of these contacts, made by Mäkinen, showed that the granites were indubitably younger; also, the porphyritic granites next to the metabasalts in the adjacent regions showed intrusive contacts. As to other granites in contact with the Bothnian schists, the age determination remained uncertain.

Later, the writer studied other metabasalts (in part even preserved as nonmetamorphic) in the Pellinge area at the southern coast of Finland, and here he found gneissose granites which were certainly older than the supercrustal rocks, being penetrated by metabasaltic dikes radiating from the areas of effusive metabasalts. Here the conditions were otherwise more complicated than more northward, because there existed two formations of metabasalts separated by the eruption of a granite (probably a hypabyssal granite of Bothnian age). This granite has, however, only a local extension.

The writer traced the metabasaltic formations in the form of dikes along the southern coast of Finland to the Aland Sea and concluded that they were everywhere intermediate in age between the gneissose granites, which they always cut as true fissure dike, and the younger granites of the

second group, which interweave them as numerous veins. As the dikes have been obviously formed near to an old earth's surface, he concluded that they marked, together with the effusive sheets of metabasalts, an unconformity in the Archean.

These conclusions were long contested, both by many Finnish and by Swedish geologists.

Then the writer discovered, a couple of years ago, a new outcrop of schists of Bothnian type which placed the matter beyond dispute. Immediately to the east of the Rapakivi area of Aland there is a synclinorium of schists of Bothnian type reposing directly on a gneissose granite, in the south also on leptitic schists penetrated by that granite. The lower part of the younger schists is formed by metapelitic and mepsammitic schists, the upper part of metabasalts which present a well preserved pillow-lava structure. The contacts with the underlying gneissose granite are everywhere quite sharp, and at one place there is a basal conglomerate with rounded pebbles of that granite.

From the basaltic formation dikes radiate into the surrounding gneissose granite, and are quite similar to those which can be traced from this area to the areas of effusive metabasalt in the east.

The divisibility of the Archean of southern Finland has thus been proved. It is obvious that there are in southern Finland supercrustal rocks which have been deposited on a basement of gneissose granites and leptitic schists after a preceding long-continued period of erosion; also, the younger schists are penetrated and in part intimately mixed up with the granites of the second group.

As the typical Bothnian formations of the Tampere (Tammerfors) region also consist of a lower division of phyllitic schists and an upper containing metabasaltic tuffs, and the former contain, in their conglomerates, pebbles of slightly gneissose granites, it seems very probable that they also are younger than the oldest gneissose granites.

These supercrustal formations of Bothnian type can be traced farther to the north, to the southeast coast of the northernmost part of the Gulf of Bothnia, and from here the same zone (the "trans-Bothnian zone") continues to the Skellefteå region in Sweden. Here also rocks occur which probably belong to the same division, but the greatest part of the Skellefteå schists seem, however, to belong to the leptites.

In general most of the Swedish schists seem, as already remarked, to belong to this oldest subdivision, while the Bothnian schists have their main extension in Finland; also, the subsequent supercrustal formations, which we will soon describe, seem to have their main distribution in eastern Fennoscandia.

Although the Bothnian formations of southern Finland have been so strongly folded and often intimately mixed up with granites, so much of their primary characters are preserved that we are able to reconstruct many of the paleogeographical features of this period. Supramarine volcanic areas have alternated with portions covered by the sea, in which sediments have been deposited whose character speaks in favor of cold climatic conditions at that time. The chemical composition of the pelitic sediments is that of glacial clays, and the layers can hardly be interpreted otherwise than as glacial, the existence of annual varves ("epetides") proving the intermittence of the sedimentation, which is probably due to a freezing of the waters in wintertime.

The Bothnian schists seem in general to have an east-west to northwest strike where they have not been reorientated by later foldings or their strike been influenced by older strikes.

If we compare the Archean rocks of Fennoscandia and North America, it must be admitted that the analogies are rather vague. The metabasalts of the Bothnian, which often show a typical pillow-lava texture, could possibly be regarded as an analogon to the immense masses of metabasalts of the Keewatin. However, there are similar rocks in Fennoscandia also connected with older, as well as with the next following formations (Kalevian and Jatulian). Quartzites or cherts, alternating with layers of magnetite, which are very similar to those that are so common among the older Archean of Canada, exist in South Varanger, in northern Norway, and have the same relation to the granites of post-Bothnian type as the metabasalts of southern Finland. In the upper parts of the Bothnian, conglomerates, often with big pebbles, are common and remind one, although not very closely, of the great conglomeratic masses of Timiskaming type in Canada.

If now the supercrustal rocks of the Bothnian of Fennoscandia are assumed to be analogous to the Keewatin, that would mean that the "leptite formation" (Svionian) of Sweden and southern Finland would have a lower position than most rocks of North America. Only in the Rainy Lake region and possibly in some parts of northern Quebec may schists of a similar character exist. In any case neither the Keewatin nor the Bothnian, etcetera, seems to be the oldest supercrustal rocks existing.

KALEVIAN AND JATULIAN AND OTHER SEDIMENTARY FORMATIONS (LADOGIAN, ETCETERA) OF THE OLD CARELO-LAPPONIAN MOUNTAIN CHAINS

Sedimentary formations.—In eastern Finland and the neighboring parts of Russian Carelia, as well as in Finnish Lapland, we find sedimen-

tary formations which are younger than the post-Bothnian granites. The conglomerates of these series contain pebbles of the granites mentioned and at some places directly lie on them. At most places, however, they lie on a basement consisting of the oldest gneissose granites.

The most important zones of these sedimentary schists stretch from the northern shore of Lake Ladoga to Lake Oulunjärvi (Uleå träsk) and farther into Lapland (*Carelo-Lapponian zone*), and from the northern shore of Lake Onega, in Russian Carelia, in a northwesterly direction (*Onega Carelian zone*); but there are also other intermediate zones.

These zones are the roots of old Precambrian mountain chains.

In the former zone schistose rocks prevail, especially phyllites and mica schists, with intercalations of quartzitic schists, dolomitic limestones, etcetera, and intrusive layers of peridotite, serpentine, metabasalts, metadiabases, metagabbros, etcetera. At the base we often find quartzites which are altered sandstones, but also rocks which have originated by the metamorphism or recementation *in situ* of the products of a secular weathering of the older rocks—breccias, conglomerates, "regenerated granites," gneisslike schists containing "eyes" of quartz and feldspar, sericitic quartzites, etcetera.

Similar schists occur also in the area north of Lake Onega.

The greatest part of these schists has been referred to the *Kalevian* system of Frosterus and Ramsay.

At the beginning the Kalevian was thought to be later in age than all the adjacent granites (besides the Rapakivi), but when the survey proceeded farther to the north granites were found over great areas which were certainly younger than the Kalevian and therefore were designated as *post-Kalevian* granites. They are sometimes in, or in the immediate neighborhood of, the greatest area in northern Finland, interwoven with Kalevian or older rocks into "migmatites."

Ladogian formation.—In the southernmost part of the Carelo-Lapponian zone we find, at the northern coast of Lake Ladoga, schists which are penetrated also by granites that quite resemble the post-Bothnian granites and seem to be intimately connected with the main areas of these granites. The schists are occasionally so strongly metamorphic that they are almost as massive as granites, and they also often contain staurolite, andalusite, and other contact minerals in abundance, while again other parts are feebly changed. The basement here consists also of gneissose granites which outcrop in oval areas surrounded by the schists. We do not here find the same bottom layers as in the typical Kalevian formations, but mainly hornblende schists which are bordered by layers of dolomitic limestone at both their contacts, also next to the

basement. These schists, whose investigation, especially in the typical area described by Trüstedt, began before that of the Kalevian, were called by the writer *Ladogian*.

It has, however, thus far never been possible to draw any marked boundary line between these schists and the formations which were later called Kalevian. Many geologists, therefore, think that they belong to one and the same formation. If that is so, then the granites which have caused the strong metamorphism of these schists at Lake Ladoga must be post-Kalevian, although petrologically similar to the pre-Kalevian granites; or, if the granites belong to the post-Bothnian group, then there must be, in the zone of sediments, a hidden unconformity between schists of different age. At some places there are in the schists conglomeratic layers which might possibly indicate a break.

A little more to the east from the Carelo-Lapponian zone there are, in the Kuopio region, at Lake Saima, sedimentary schists which certainly correspond to the theoretical definition given to the Ladogian, since they lie on a basement of gneissose granite and are certainly penetrated by granites belonging with those of the neighboring great central area of post-Bothnian granite. These schists, which have been studied by Wilkman (who has also mapped a great part of the Kalevian areas), consist mainly of mica schists and quartzites. They become at all sides mixed up with granitic veins, thus passing into migmatites which are in contact with the Kalevian schists more to the east. The boundary is very indistinct, but Wilkman has stated that the peridotites, which are nearly connected with the Kalevian schists, penetrate the veins of post-Bothnian granite, and he has also found, more to the north, Kalevian schists lying directly on granites which certainly are connected with those of the central area. There are thus indications of an unconformity between two formations of schists, one older and one younger than the post-Bothnian granites. The break may, however, be rather inconspicuous where sediments of similar character are in contact and both have become metamorphic in almost the same degree.

The relations of the Kalevian and the schists of Ladogian type show a certain analogy to those between the Huronian and the Grenville series of Canada.

It appears from the foregoing that the schists of Kuopio, and possibly also the Ladogian at Lake Ladoga, lie, as to their age, between the granites of the first and the second group, just as the Bothnian schists of southwestern Finland. It is very difficult to say which of them is younger. There are mica schists in the basement of the Bothnian which might possibly be of the same age as the Kuopio schists, and the effusive rocks

intercalated with the Bothnian schists seem again to have a close connection with granitic and gabbroid rocks that penetrate the schists of Kuopio. In general, the Bothnian was a time of volcanism and unrest, while the character of the schists in eastern Finland shows that they have been deposited during a time of quiet sedimentation.

While those facts seem to speak in favor of a younger age of the Bothnian, the close connection of the Ladogian schists at Lake Ladoga with the younger Kalevian schists could again be quoted as a reason for assuming a younger age. Finally, there are "varved" sediments both in the Bothnian and the Ladogian, which fact could possibly be quoted in favor of the assumption that both would only be facies of one supercrustal formation.

However the question about the relation of the Kalevian and the Ladogian may be decided, it seems probable in any case that the Carelo-Lapponian mountain chain contains components of different age. In Lapland we find in Kittilä, in close connection with rocks of Kalevian type, ore-bearing cherts which are very similar to those of South Varanger, in northern Norway, mentioned above. These are at the latter place associated with conglomerates containing pebbles of gneissose granites, but are penetrated by granites of post-Bothnian type which have a wide extension also in the Finnish Petsamo area and in the peninsula of Kola. If the ore-bearing rocks of Kittilä are to be correlated with these Norwegian rocks, they are thus to be regarded as pre-Kalevian. There also seem to occur in Lapland basic effusive rocks that are older than granites prior to the post-Kalevian.

Jatulian formation.—Now there occurs among the sedimentary formations which are certainly later in age than the post-Bothnian granites, besides the Kalevian, another formation which has a rather different character. The rocks in question occur especially in Russian Carelia north of Lake Ladoga, but stretch also over to the Finnish side of the boundary. Similar rocks have also a great extension in northern Finland and Lapland.

These formations consist of a very regular succession of rocks, beginning with sandstonelike quartzites, often showing well preserved ripple-marks and containing basal conglomerates at the bottom. Residual deposits play a lesser rôle than in the Kalevian. The quartzites are, however, often feldspathiferous. On the quartzites follow dolomites, which are sometimes cavernous. At one place there has been found in them, by Metzger, a fossil-like structure called *Carelozoon jatulicum.* The uppermost part of the formation is formed by phyllites in which is found the peculiar coal, occurring also at Lake Onega, that has been

called *schungite*, and which is analogous to a coal found as dikes in the Sudbury region. Metagabbro and metadiabases have been intruded between the layers of the sediments or next to their basement. When surrounded on all sides by gneissose granites, these formations occur in very regular synclines.

These formations are feebly metamorphic and devoid of granitic intrusions. They possess in general very much the same character as the Huronian of the original area at Lake Huron.

Because of the great difference in their primary constitution, as well as in the character and grade of metamorphism between these rocks and the "Ladogian" schists at Lake Ladoga, the writer referred the former in 1897 to a special system which he called *Jatulian*. Wilhelm Ramsay later studied similar rocks in Russian Carelia and used for them the same designation. Ramsay regarded the uppermost part of the formation, comprising the phyllites containing schungitic coal, as a separate formation, which he called *Onegian*. In Finland they have been referred to the upper Jatulian.

The Jatulian (and Onegian) of Russian Carelia are directly underlying the Jotnian sandstones of this area.

The Jatulian was from the beginning thought to lie unconformably on the Kalevian. Ramsay had found in Russian Carelia a section where there were sedimentary schists below the bottom conglomerates, and in the Kittilä region, in northern Finland, a similar section was studied by Tanner and others.

Eskola, however, later explained the succession in Russian Carelia as conformable, false bedding having disguised the features of the lower portion, which he designated as "Sariolian."

The Jatulian formations which stretch over from Russian Carelia into eastern Finland occur here mainly in synclines within the great area of granitic gneisses resting on them, but also along the eastern boundary line of the schists of Kalevian and Ladogian type where these latter are in contact with the gneissose area. The quartzites (at some places also dolomites) of Jatulian type form a zone of changing breadth along the contact of the schists. In part it also sends out protuberances into the gneissose area.

There are basal areas of granitic gneisses also west of this borderline, sometimes immediately west of the quartzitic zone, but they are not surrounded by a rim of these quartzites, as should be expected if these underlay the schists. On the contrary, the quartzites are commonly entirely absent. This sudden disappearance of the quartzite and associated rocks, which are so persistent and uniform in character in the

region east of this borderline, has been explained by the assumption that the rocks of Jatulian type have originally overlain the Kalevian, and that they have been folded in between them and their basement. The apparently overlying position of the Kalevian should be due to some kind of overthrust. There are also elsewhere localities where the basement of the Kalevian has certainly been thrust over the schists.

At one place pebbles of schists similar to those of the Kalevian zone have been found in the conglomerates of the Jatulian, but in general they contain only pebbles of gneissose granite, of quartzite, and of a massive tourmaline-bearing granite of post-Bothnian type.

For the reasons quoted above, the sandstonelike quartzites of Jatulian type and associated rocks have been separated from the Kalevian by the mapping of the Geological Survey, partly from petrological differences and partly from their relations to other rocks.

Mäkinen, however, has propounded the view, as to the sedimentary area of Kemi, in northern Finland, on the northern coast of the Gulf of Bothnia, that the rocks mapped by Hackman as Kalevian and Jatulian only differ in the strength of the metamorphism which they have undergone, all being older than the so-called post-Kalevian granites.

Later, Eskola expressed the opinion that the conditions of the Jatulian and Kalevian of eastern Finland were similar, and that the underlying position of the former was not apparent, but real. The occurrence of conglomerates in the schists near to the quartzites and with quartzitic pebbles seems to add importance to this line of argument.

As to northern Finland, Hackman has stated that there exists in Kittilä an indubitable unconformity between quartzites, schists, and metabasites of Kalevian type and an overlying formation of sandstone-like quartzites of Jatulian type, whose basal conglomerates contain pebbles of all the underlying rocks. Their boundaries are cut by the contacts of the quartzites. Hackman and Wilkman think that there is a similar unconformity in Kuusamo, farther to the east, and the former also maintains that it exists in the Kemi area, although being there of less distinct character.

As to the relations of the rocks of Jatulian type to the so-called post-Kalevian granites, Hackman leaves it undecided whether their last portions may be younger than these sediments. In any case, any intrusions in them have thus far never been found, as little here as elsewhere in the Jatulian. There is only one exception where a lenticular mass of tourmaline-bearing pegmatite and quartz was observed, by a non-geologist, in a pit. This absence of granite may, however, either be due to a younger age of the sediments or also to the circumstance that these have been protected against intrusion because lying in a resistent area.

At the present time we may take it for granted that Kalevian and Jatulian rocks are later in age than the granites of post-Bothnian type and the sediments which they penetrate, but their relations to each other still remain undecided.

In any case, we have now arrived, by the study of these stratigraphic questions, to a stage where the remaining problems are few in number and may be sharply defined. It will therefore be possible definitely to solve them by a continued study of the clue regions whereby the contact relations, the petrology of the sediments, and the geotectonics ought to be taken into consideration. If the typical areas in Russian Carelia were again to be available to the study by Fennoscandian geologists, the definite solution would probably be near at hand.

These formations, correlated in Finland to the Kalevian and Jatulian, have long been regarded in Russia as Devonian and Carbonian in metamorphic habit; but this opinion is probably now abandoned.

Some questions of nomenclature.—Eskola has proposed preliminarily to use the name "Carelian" for all the sedimentary formations of the Carelo-Lapponian zones, thus including the Kalevian, Jatulian, and Ladogian. If the latter contains also rocks older than the post-Bothnian granites, it does not seem practical to use a term covering all these rocks, which are possibly divided by one of the greatest unconformities existing. Väyrynen, again, wishes to call the pre-Kalevian quartzites "Kainuuan." It seems to the present writer most desirable not to introduce too many new names before the theoretical questions are decided, and better to apply the older names as far as possible, although possibly with a modified meaning. Else a great confusion will originate, especially by the use of the older maps.

Kalevian, as the least strictly defined, and thus most elastic designation, seems in doubtful cases preferable, if a common name is to be used.

Possible correlation with other formations.—The Kalevian-Jatulian formations are in type very similar to the Huronian formations of North America. If we look for analogies among them to the glacial deposits described by Coleman, such are not entirely wanting. At the river Oulunjoki, in northern Finland, very polymict conglomerates exist in this series, and the same seems to be the case, according to Eskola, also in Russian Carelia. The metamorphism of these sediments is due to a period of disastrophism, connected with the protrusion of granites, which may in a certain way be said to be analogous to the Algoman granites of the region north of Lake Superior; but the rocks of Kalevian type in Fennoscandia have in part been much more intensely granitized than the Huronian rocks generally are.

In northern Sweden there are, for example, near to the ore-bearing rocks of the Kiiruna region, conglomeratic and quartzitic rocks which may be correlated with the Kalevian or Jatulian rocks on the Finnish side, and in southwestern Sweden we find in Dalsland a thick series of conglomerates, quartzite, phyllite, basic eruptives, etcetera, which have undergone a strong folding. This formation has been referred by Högbom to the Jatulian, under the assumption that the folding is older than the Jotnian sandstone of Dalecarlia, which is still lying horizontally.

Törnebohm, again, thought it possible that the Dalsland formation could be of the same age as that sandstone which is of Keweenawan type. If this assumption be correct, we should here have indication of a post-Jotnian folding which is not felt with equal strength anywhere else in Fennoscandia. The opinion of Högbom seems, however, much more plausible.

The quartzites of Jotunheim and Krageroe, in Norway, also present many similarities to the formations now described.

Limitation of the Archean

When we have to do with rocks of Jatulian type, reposing upon a highly crystalline basement, there seems to be a very sharp demarcation line between rocks of Archean and rocks of Proterozoic type. Högbom once said that this unconformity perhaps indicates the greatest break existing in geological history.

The Kalevian has, again, only locally this same character. Where it is intimately interwoven with granites, it resembles very much the typical Archean formations. It has therefore alternately been referred to the Archean and the Proterozoic. If there is a close connection between this formation and the Jatulian, then it seems most practical to refer both to the Proterozoic.

Areas of Relative Stability existing at a very early Epoch

In Finland all geologists agree on the fact that the eastern area of gneissose granite has been an area of relative stability since very remote times. The hypothesis promoted in Sweden by De Geer, according to which its character would be due to dynamometamorphism in late Precambrian time, has here no adherents. It is this great stability which has preserved the old sediments lying on it from destruction and a stronger metamorphism.

In general, it is obvious that already in Kalevian and contiguous post-Kalevian time the movements of the earth's crust were local, not univer-

sal. The strongest post-Kalevian folding, accompanied by the eruption of granites, has only affected certain areas.

But also the post-Bothnian granitic eruption and folding has not been ubiquitous. Great areas both in Sweden and Finland, where it, however, had its greatest extension, and especially in the easternmost part of Fennoscandia, have not been much affected by it.

The oldest gneissose granites seem to have a greater extension, but they may genetically comprise very different things. The occurrence of well preserved supercrustal rocks, also older than these granites, seems to indicate that also by these foldings some portions of the crust were left undisturbed.

Last Period of the Precambrian—Jotnian

After the close of the last movements in the Carelo-Lapponian mountain chains, there has been a long time of uninterrupted erosion while Fennoscandia has been part of a continent. Of the sediments formed during that period only scanty remains exist.

A new period of unrest began by the eruption of the Rapakivi granites, preceded by that of anorthositic rocks. Effusive quartz porphyries occur, as already said, in association with the Rapakivi granites, and at one place there is a conglomerate immediately below these volcanic sheets.

The laccolithic mountains of granite which ought to have existed were soon again eroded, and then began the deposition of the Jotnian sandstones, which lie in part directly on the Rapakivi. These sandstones are mainly red and possess the same climatological character as the Keweenawan of northern America and the Devonian and Triassic sandstones. These "Oldest Red Sandstones" may probably be correlated on that criterion all over the world. The remains of this sandstone are now found in Fennoscandia at the White Sea, at Lakes Onega and Ladoga, at both sides of the Gulf of Bothnia, in middle Sweden and Dalecarlia, and in the adjacent part of Norway. It is often intercalated with diabases. Its upper layers seem to be very near in age to the Cambrian.

These formations are generally almost horizontal, but there is one of them, the Almesåkra formation of southern Sweden, which has been subject to folding that also has affected the diabase intercalated with it.

These movements have, however, not been very strong.

The eruption of the Rapakivi granites seems to mark the last period of unrest in this region before the Caledonian folding set in. The disturbances caused by the eruption of the Rapakivi were quite local, and it has not caused any general disastrophism in the surroundings. In

itself, however, it marked an event of great and probably world-wide importance.

Typical Rapakivi granites, showing quite the same peculiar texture as in Fennoscandia, and also there connected with anorthosites and with presumably Precambrian sandstones of Keweenawan type, occur in southern Russia. Eskola has also found Rapakivi at Lake Baikal, in Siberia; and, further, we find in Korea over great areas granites, passing by gradations into quartz porphyries, which seem to have broken forth almost at the same epoch.

Thus there seem to have been analogous eruptions over great parts of the globe in late Precambrian time, in general before the deposition of the sediments of Jotnian-Torridorian-Keweenawan type.

If the Killarney granite of Canada is really younger not only than the basic rocks preceding the Keweenawan (with a position possibly analogous to that of the anorthosites and diabases preceding the Rapakivi in Fennoscandia), but also than the basaltic rocks intercalated with the formation mentioned, then they are probably somewhat younger than the Rapakivi and other granites to be correlated with that rock. Moreover, the Canadian granites differ from them by being typical plutonic granites, while the others are hypabyssal and in part effusive.

The nearness of the Keweenawan-Jotnian period to the Cambrian leaves a very short time for these events assumed to have taken place in Canada. In any case, they have no stricter analogy in northern Europe, since, as appears from the foregoing, it is very clear that the metamorphism of the rocks of Huronian type in Fennoscandia has taken place in a very early period and was connected with the eruption of granites which are certainly much older than the Rapakivi.

Concluding Remarks

As will be seen from this account of the stratigraphical study of the Precambrian of Fennoscandia, much work is still needed before the complicated geological structure of this territory will be more completely unraveled. If we remember that less than half a century ago it was still regarded as doubtful whether any originally clastic rocks existed in the crystalline parts of it, it must be admitted that we have advanced a good deal since that time. By comparing the evidence won from this territory with that collected in other parts of the world, it seems obvious that the Precambrian sedimentary formations represent a length of time comparable, if not superior, to that with which the Postcambrian sequence is measured; and, anyhow, these oldest rocks are

still treated in many textbooks of geology as if they were an unimportant appendix to the geological record from Postcambrian time!

It is highly desirable that more interest should be devoted to the comparative study of these formations in different parts of the world. As their correlation meets so much greater difficulties than that of the fossiliferous systems, some kind of international organization of their study is very necessary. It would certainly be a fruitful study, both for theoretical and practical purposes, the latter particularly because the Precambrian includes many of the richest mineral deposits existing.

As to theoretical geology, there is hardly any of its fundamental questions that has not a close connection with or can not be properly elucidated by a detailed study of those formations which originated during the remotest periods and have in great part once been in the lowest position within the earth's crust.

Although this paper has attained a greater length than might be desirable, the writer has been able only to touch lightly on questions of general interest for the proper treatment of which a whole textbook on Precambrian geology would be necessary. It would be a geology of what lies beyond—behind—what is commonly regarded as the beginning of geological history and below the deepest sections through rocks of younger formations. In those rock-masses which once have been so deep-seated, processes have taken place which exceed in strength all metamorphism active nearer to the surface. We are able here to study the origin of magmas and their differentiation at great depth, and to reveal by a purely inductive study what lies below the mountain chains. We here regard the phenomena *from below*, as it were, and are thus able to find the origin also of many things that have appeared at the surface and to elucidate also, from that special point of view, the later history of our globe.

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GEOLOGIC RECONNAISSANCE IN THE PIEDMONT OF VIRGINIA

BY ANNA I. JONAS

(Read before the Society December 27, 1926)

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INTRODUCTION

In the spring of 1926 the writer began a geological reconnaissance of that part of Virginia [2] which lies between the Coastal Plain region on the

[1] Manuscript received by the Secretary of the Society February 28, 1927.
Part of the symposium on Precambrian geology. Read by W. A. Nelson.
[2] Published with the permission of the State Geologist of Virginia.

east and the Great Valley on the west, and had by December, 1926, carried the work in part of the area to James River. The region comprises the Piedmont and Blue Ridge provinces. At Potomac River the Blue Ridge Province extends from Catoctin Mountain west to Harpers Ferry and is coextensive with the Catoctin-Blue Ridge anticlinorium, which is continuous from near Dillsburg, Pennsylvania, across Maryland, Virginia, the Carolinas, and Georgia. The eastern boundary is the east front of Catoctin and Bull Run Mountains and a more or less continuous series of mountains which extend from Bull Run and Clark Mountains southward to the James River near Lynchburg.

South of Bull Run Mountain local custom and certain physiographers have included in the Blue Ridge Province only the "Blue Ridge" proper, or the western part of Catoctin-Blue Ridge anticlinorium. That part of the anticlinorium which lies east of the Blue Ridge is regarded by them as part of the Piedmont Province. The Piedmont of Virginia in that sense comprises not only the southern extension of the Piedmont of Maryland, but also a large part of the anticlinorium, which has had a different geologic history from the area east of it.

Piedmont Province of Maryland and Pennsylvania

The rocks of the Piedmont of Maryland extend southward into Virginia, and their stratigraphy [3] in Maryland and Pennsylvania will be briefly summarized before that of the similar belt in Virginia is discussed.

The Piedmont of Maryland and Pennsylvania southeast of the Chester, Lancaster, and York valleys contains a broad belt of Precambrian crystalline schists which lies south and east of Paleozoic rocks, and these, together with the Precambrian schists, are overlain by Triassic rocks. The Precambrian crystallines extend from the Delaware River through Philadelphia, Baltimore, and Washington and form a belt which is about 40 miles wide in northern Maryland and only about 16 miles at the Potomac River, a narrowing produced by the overlapping of Coastal Plain sediments on the east and Triassic rocks on the west.

The oldest formation is the Baltimore gneiss, a thoroughly recrystallized rock of sedimentary origin and granitic aspect, containing micaceous and hornblende layers. In Maryland it is intruded by a granite, the Hartley augen-gneiss.

The Glenarm series which unconformably overlies the Baltimore gneiss is a series of thoroughly metamorphosed Precambrian sediments which

[3] E. B. Knopf and A. I. Jonas: Stratigraphy of the crystalline schists of Pennsylvania and Maryland. Am. Jour. Sci., vol. v, 1923, pp. 40-62.
A. I. Jonas: Precambrian rocks of the western Piedmont of Maryland. Bull. Geol. Soc. Amer., vol. 35, 1924, pp. 355-364.

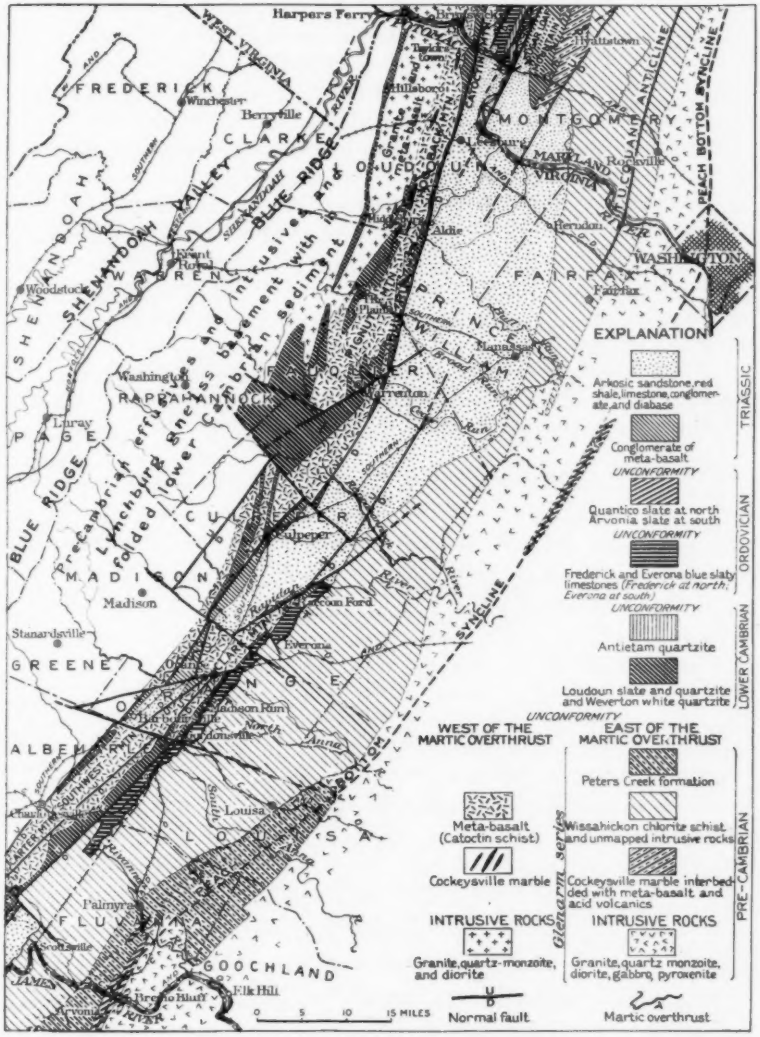

FIGURE 1.—*Geologic Map of northeastern Virginia*

By Anna I. Jonas.

comprise, from the bottom up, the Setters formation, the Cockeysville marble, the Wissahickon formation, and Peters Creek formation. Cardiff conglomerate and Peach Bottom slate overlie the Peters Creek formation in the Peach Bottom syncline. Because of lack of fossils, and therefore of positive knowledge of the age of these formations and of any observed unconformity at the base of the Cardiff conglomerate, that formation and the Peach Bottom slate have been included in the Glenarm series.

Igneous rocks ranging from granite to gabbro have intruded the Baltimore gneiss and the Glenarm series in the southeastern part of the belt; in the northwestern part volcanic rocks, largely basaltic in composition, were poured out during the deposition of the Glenarm series and are interbedded with Cockeysville marble and the basal part of the Wissahickon formation.

The Glenarm series, as well as the underlying Baltimore gneiss, is considered to be Precambrian in age because it is overlain unconformably by Lower Cambrian rocks of the Sugar Loaf syncline.

Piedmont of northern Virginia east of the Catoctin-Blue Ridge Anticlinorium

General statement

This part of the Piedmont of Virginia contains the southwestward continuation of the rocks of the Piedmont of Maryland. These rocks comprise Precambrian crystalline schists of the Glenarm series, Triassic rocks which lie northwest of them in northernmost Virginia and limestone exposed in a narrow valley south of Rapidan River. This limestone valley lies east of the Catoctin-Blue Ridge anticlinorium and west of the Precambrian schists, as does the limestone of the Frederick Valley of Maryland (see figure 1).

The southwestward continuation of the Baltimore gneiss and overlying Setters formation, Cockeysville marble and the eastern (or oligoclase-mica schist) facies of the Wissahickon formation, are covered south of Laurel, Maryland, by Coastal Plain sediments, and their occurrence and extent in eastern Virginia has not yet been investigated.

Precambrian rocks

Wissahickon formation.—The western (or albite-chlorite) schist facies of the Wissahickon formation lies west of the Peach Bottom syncline and extends from Maryland into Virginia. It occupies a narrow belt west of Washington and extends southwestward from the Potomac to the James River and far southward. This schist area crosses the Rappahannock and Rapidan rivers west of their junction. North of Rapidan

River the northwestern border of the Wissahickon schist is formed by Triassic rocks, south of that river by a belt of blue slaty limestone called Everona limestone. Intrusive rocks and the Peters Creek formation border the Wissahickon schist on the southeast.

The albite-chlorite schist is a finely crystalline, sparkling, bluish-green schist composed of chlorite, muscovite, quartz, and albite. The albites occur only in certain beds and are fine-grained porphyroblasts with many inclusions of other minerals. The greater part of the formation in northern Virginia is a chlorite muscovite schist with a variable quartz content. The formation is closely folded and possesses a slaty cleavage.

Peters Creek formation.—From a brief study of the quartzite and schist exposed along the James River near Bremo, the writer has tentatively correlated these rocks with the Peters Creek formation of Pennsylvania and Maryland. This quartzite-schist series outcrops in Virginia southwest of North Anna River and lies southeast of the area of Wissahickon albite-chlorite schist already described. It is bounded on the southeast by igneous rocks and Wissahickon mica schist, and is in strike with the Peters Creek formation of Maryland, but stratigraphic continuity is broken south of Patapsco River, in Maryland, by the Sykesville granite and other granites south of it in Virginia.

Igneous rocks.—The Wissahickon schist and Peters Creek formation are intruded by granite, granodiorite, gabbro, and more basic dikes of peridotite and pyroxenite which are altered to serpentine and amphibolite schist. They are intercalated also with volcanic flows. The widest area of granites is in the vicinity of Fredericksburg and Richmond. The intrusive rocks have been considered to be Precambrian in age because they show effects of considerable metamorphism and, so far as known, do not cut Paleozoic rocks. Londsdale [4] describes small areas of post-Cincinnatian granite near Fredericksburg and stringers of fresh granite in the Quantico slate. As yet these younger granites have not been examined by the writer.

ORDOVICIAN ROCKS

Arvonia slate.—In the area from north of the Rivanna River to south of the James, between Palmyra and Bremo, there are exposed blue slates which unconformably overlie Peters Creek formation and Precambrian granite, with a basal conglomerate present in part of the area. These slates have been previously mapped and described,[5] but no name has

[4] J. T. Lonsdale: Jour. Geol., vol. xxx, IV, H 2, 1926, pp. 159-166.

[5] N. H. Darton: Fossils in the Archean rocks of Central Piedmont, Va. Am. Jour. Sci., vol. xliv, 1892, pp. 50-52.
Thomas L. Watson and S. L. Powell: Op. cit.
Stephen Taber: Geology of the Gold Belt in the James River basin. Virginia Geol. Survey Bull. VII, 1913, pp. 39-52.

been given them, so far as is known. The writer proposes the name Arvonia slates for these beds. They are extensively quarried for roofing slates, and as early as 1892 fossils [6] were pronounced by Walcott to be Trenton-Lorraine. Watson [7] in his 1911 report quotes Bassler as stating the fossils from Arvonia to be of middle Cincinnatian age, but later Bassler [8] has concluded that they are probably of Chazy age.

They are in strike with the Quantico slate of northern Virginia, which unconformably overlies Precambrian schists and granite and in which Ordovician fossils [9] have also been found.

The Arvonia and Quantico slate lie in the southwestward extension of the Peters Creek syncline. In Maryland and Pennsylvania similar slates, the Peach Bottom, which occur in the same syncline, have yielded no fossils and have been placed in the Precambrian in the absence of positive evidence to the contrary. The presence of slate of known Ordovician age in the Peach Bottom syncline in Virginia is a matter of interest.

Everona limestone.—A narrow belt of blue slaty limestone is exposed from Mitchells Ford, on Rapidan River, to southwest of Rivanna River near Charlottesville. This limestone area has an average width of 2 miles and occupies a valley northwest of the Wissahickon schist and southeast of the Triassic border fault of the Catoctin-Blue Ridge anticlinorium. The name Everona is taken from a small village in Orange County, where the limestone is exposed in a small quarry north of Mountain Run.

The limestone is blue, crystalline, with slaty partings, closely crumpled, with breaks cemented by secondary white calcite. It is interbedded with thin, blue, only slightly calcareous slates. The slates are a considerable part of the formation and form ridges between the limestone valleys with a soil of blue slate slivers streaked with buff bleached bands. This blue limestone and slate formation is lithologically similar to the Frederick and Conestoga limestones of Maryland and Pennsylvania. It is in strike with the Frederick limestone of Frederick Valley, Maryland, which lies 40 miles to the north. From the fossil content both Frederick and Conestoga limestones are considered to be of probable Upper Chazy age. Poorly preserved fragments of trilobites have been collected by the writer from the sandy beds near the contact of blue limestone south of Orange, but Mr. E. O. Ulrich found that they were not recognizable

[6] N. H. Darton: Idem.
[7] T. H. Watson: Loc. cit.
[8] Personal communication.
[9] N. H. Darton: Fredericksburg folio (No. 13). Geol. Atlas U. S., U. S. Geol. Survey, 1894, p 4.
Thomas L. Watson and S. L. Powell: Fossil evidence of the age of the Virginia shales. Am. Jour. Sci., vol. xii, 1911, pp. 33-44.

even generically, and hence they do not help to establish the age of the beds. The marked lithologic resemblance between the Everona limestone of Virginia and the Frederick limestone and the occurrence of the Everona limestone in Virginia 40 miles south of the Frederick Valley, along the same strike and just east of the Catoctin-Blue Ridge anticlinorium, strongly suggests that the Everona limestone is probably of the same age as the Frederick limestone.

RELATION OF WISSAHICKON SCHIST TO THE EVERONA LIMESTONE

The Ordovician limestone of Frederick Valley and older Paleozoic rocks to the east of it in Maryland have been overridden by a block of Precambrian and Lower Cambrian rocks, which have moved northwest. This overriding mass is a part of the great Martic overthrust which extends from near Philadelphia to the Potomac River. From Mitchells Ford, Virginia, southward Precambrian Wissahickon schist, which in Maryland is a part of the overthrust mass, lies southeast of Everona limestone. It is thought probable, therefore, that the contact of the Wissahickon schist and Everona limestone is a fault contact, as is the contact of the Frederick limestone and Precambrian rocks in Maryland, and that this overthrust fault is the southwestward extension of the Martic overthrust.

Catoctin-Blue Ridge Anticlinorium

GENERAL DESCRIPTION

In Virginia this anticlinorium lies west of that part of the Piedmont Province just described. It is part of the great Appalachian mountain uplift which extends northeastward through the Reading Hills, in Pennsylvania, the Highlands of New Jersey and New York, and the Green Mountains of New England.

The area in Maryland and in Virginia north of a line connecting Luray and Warrenton has been described by Keith [10] as "The Catoctin Belt." Little has been published concerning the stratigraphy of the rocks of the anticlinorium to the southward. At Potomac River the anticlinorium extends from Catoctin Mountain to Harpers Ferry. At James River it extends from a little east of Lynchburg to Balcony Falls. Its southeastern boundary is a series of Triassic normal faults; its northwestern boundary is a thrust-fault of Paleozoic age. The anticlinorium has a core of metamorphosed Precambrian igneous rocks, both plutonic and effusive, with an increasing amount of Precambrian sedimentary gneiss and schist exposed from Madison County to the southwest. Lower Cam-

[10] Arthur Keith: U. S. Geol. Survey, Fourteenth Ann. Rept., 1893, pp. 293-395.

brian sedimentary rocks of the Loudoun and Weverton formations are infolded in synclines in the older rocks and form Catoctin and Bull Run Mountains on the east and Short Hill (the southeast extension of South Mountain) and the western front of the Blue Ridge, except where they are cut out by thrust-faulting.

PRECAMBRIAN ROCKS

Igneous rocks—Metabasalt and other effusive rocks.—Rhyolite, andesite, and basalt occupy large areas in the northern part of the anticlinorium in Virginia,[11] but basalt, or Catoctin schist, as it was called by Keith, makes up the greater part of the effusive rocks. The basalt is a crystalloblastic green amphibolite which contains remnants of feldspar, hornblende with some original pyroxene, secondary quartz, epidote, and chlorite. It occurs as a massive amygdaloid as well as a hornblende schist and may be called a metabasalt.

The formation makes a border on both sides of the anticlinorium nearly to James River, that is, nearly to Lynchburg on the southeast and Balcony Falls on the southwest side. The southeastern border, which is a wide area at Potomac River, diminishes in width southwestward until cut off entirely by the mountain border fault a few miles northeast of Lynchburg.

Intrusive rocks—Granite.—Granite and metabasalt, into which the granite is intruded, comprise the greater part of the Precambrian rocks of the anticlinorium north of Washington County. Keith distinguishes six varieties[12] in this area.

From Madison County southward quartz monzonite and hornblende gneiss outcrop in the mountains of the central part of the anticlinorium. The quartz monzonite is a coarsely prophyritic biotite quartz gneiss with schistose layers. It intrudes the hornblende gneiss (metagabbro), but its relation to the effusive rocks is not yet known.

Hornblende gneiss.—This rock is a metagabbro of metapyroxenite, both massive and schistose, intrusive in the Lynchburg mica gneiss, to be described later. Soapstone, which has been derived from a facies of this basic intrusive, is of considerable economic importance in the region south of Charlottesville.

Sedimentary rocks—White marble.—Little Precambrian sedimentary rock is exposed in the anticlinorium north of Madison County. From Potomac River southward nearly to Aldie, white marble occurs in a narrow belt. It is a white crystalline marble, lithologically like the

[11] Arthur Keith: Loc. cit., pp. 302-306.
[12] Arthur Keith: Loc. cit., p. 299.

Cockeysville marble in Maryland northwest of the Peach Bottom syncline. Like the Cockeysville marble of the western Piedmont of Maryland, it is exposed in anticlines and underlies the metabasaltic flows of Precambrian age. It has been mapped by Keith [13] as a part of the Loudoun formation, but because of its lithology and its structural relation to the metabasalt, the writer concludes that it is more probably a Precambrian marble which may be correlated with the Cockeysville marble.

Lynchburg gneiss.—This formation, typically exposed [14] at Lynchburg, is here called the Lynchburg gneiss. It is a fine-grained biotite quartz gneiss and schist in part garnetiferous. It is intruded and injected by hornblende gneiss, gabbro, and quartz monzonite. It is widely exposed from Madison County southward and is the oldest known rock of the anticlinorium. It may prove to be the equivalent of the Carolina gneiss of the Blue Ridge uplift south of Virginia.

LOWER CAMBRIAN ROCKS

The Loudoun formation and the Weverton quartzite occupy four synclines in the anticlinorium. The Catoctin Mountain syncline is faulted out by the mountain border fault east of Warrenton. The Short Hill syncline extends nearly to Orange. A third parallel syncline lies west of Charlottesville and extends to Amherst. Only the western belt of Lower Cambrian rocks on the western border of the anticlinorium passes south of the James River. The Loudoun formation is exposed in these synclines throughout their length, but the Weverton quartzite does not occur in any of the three easterly syclines south of Bull Run Mountain.

The Loudoun formation varies considerably lithologically and comprises sericitic slate, black graphite slate, black ferruginous quartzite, green sericitic quartzite, coarse arkosic quartz conglomerate, and arkosic biotite quartzite. Blue quartz grains are abundant throughout the formation. Some previous workers have included in the Loudoun formation the Precambrian Lynchburg gneiss, which, however, can readily be separated from the Loudoun because of its greater degree of metamorphism and the igneous intrusions of Precambrian age which it contains.

TRIASSIC INBREAK IN THE EASTERN PART OF THE ANTICLINORIUM

The Triassic rocks of northern Virginia extend south from the Maryland-Virginia line to Barboursville and lie east of the border faults of Catoctin and Bull Run Mountains. On the southeastern side and north of Rapidan River they overlie unconformably Wissahickon schist. The

[13] Arthur Keith: Loc. cit., p. 324.

[14] T. H. Watson: Granites of the southeastern Atlantic States. Bull. 1426, U. S. Geol. Survey, 1910, p. 81.

presence of limestone conglomerate in the western part of the Triassic area in northern Virginia indicates that they overlie limestone on that side. The belt is 18 miles wide from the Potomac to south of Manassas, where the eastern boundary curves west and southwest and the belt narrows to 9 miles south of Rappahannock River. South of the mouth of Hazel River, on Rappahannock River, and of Raccoon Ford, on Rapidan River, Triassic rocks lie on metabasalt for a distance of 25 miles. These rocks narrow to 2 miles in width at the southwest end near Barboursville.

The lowest beds on both sides of the area south of Hazel River and Raccoon Ford are a coarse conglomerate of breccia made up largely of angular fragments of metabasalt, many of them of boulder size, which probably were not carried far from their source. Besides fragments of metabasalt, the conglomerate contains pebbles of quartz and granite and all are cemented by red ferruginous matrix. The fragments of metabasalt in the conglomerate are identical in character with the metabasalt of the anticlinorium, and although the Triassic rocks of the areas which contain the conglomerate are bounded by faults, it is evident that the adjacent metabasalt furnished the material for the conglomerates.

The Triassic rocks are bounded on the west throughout by normal faults, and south of Raccoon Ford the southeastern boundary is also a fault. In general they are cut by several cross-faults, which have broken the Triassic area into angular blocks and have offset the boundary faults and the underlying rocks.

The Triassic rocks south of Hazel and Rapidan rivers lie in a graben within the area of the anticlinorium and they owe their preservation to this drop-faulting. The Triassic sediments of this northern belt of Virginia, therefore, lie partly on the older rocks of the eastern part of Piedmont Province and partly on those of the Catoctin-Blue Ridge anticlinorium. The other Triassic areas farther south in Virginia are within the area of that part of the Piedmont Province which lies east of the Catoctin-Blue Ridge anticlinorium.

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